

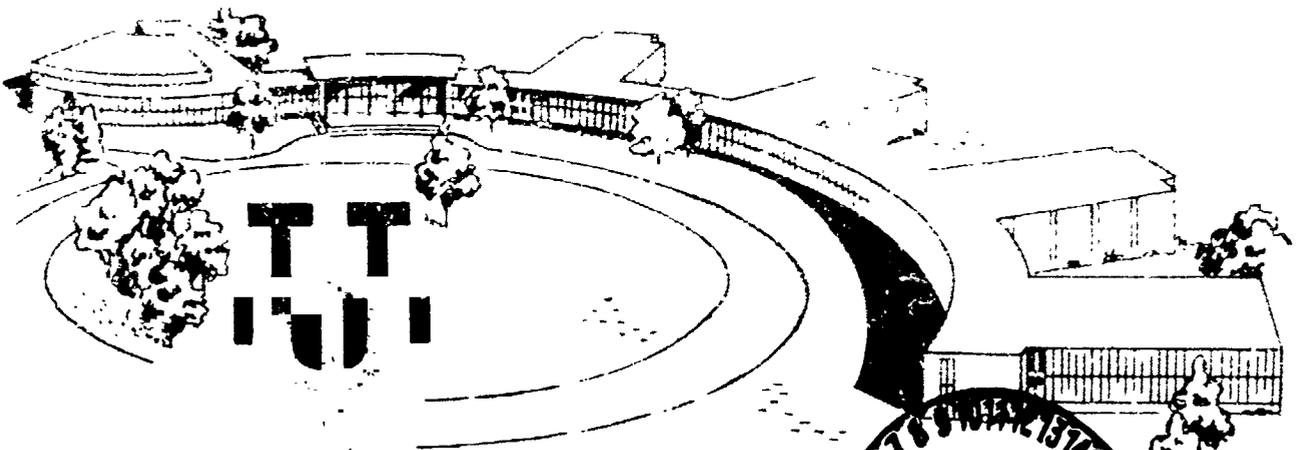
MANAGEMENT PHILOSOPHIES AS APPLIED TO
MAJOR NASA PROGRAMS (Tennessee Univ.
Space Inst., Tullahoma.) 94 p HC \$4.75

N75-14633

CSSL 05A

G3/81

Unclas
06513



THE UNIVERSITY of TENNESSEE SPACE INSTITUTE

Tullahoma, Tennessee

**MANAGEMENT PHILOSOPHIES AS APPLIED
TO MAJOR NASA PROGRAMS**

By

**Konrad K. Dannenberg
Associate Professor
of
Aviation Systems**

**The University of Tennessee Space Institute
Tullahoma, Tennessee**

**This Research was Performed under National
Aeronautics and Space Administration (NASA)
GRANT NO. NGR 43-001-116 (SUPPLEMENT NO. 2)**

October, 1974

ACKNOWLEDGEMENTS

The research for this study on "Management Philosophies as Applied to Major NASA Programs" was performed under NASA Grant No. 43-001-116 to the Space Institute of the University of Tennessee.

The author wishes to express gratitude and appreciation for personal attention, stimulation, and assistance to Mr. Jerome D. Morris of the office of University Affairs in NASA Headquarters, and personnel at many field centers too numerous to mention by name.

Within the Space Institute the guidance, cooperation and support of Dean, Dr. B. H. Goethert; Graduate Research Assistant Richard H. Smith; and the very patient secretary Mrs. Marie Henderson, were of invaluable help to this study.

The author hopes that these research results will be of help to the manager of future technology programs as they are being applied to the solution of mankind's world wide problems.

Table of Contents

<u>Section</u>	<u>Page</u>
A. Introduction	2
B. Background	5
C. Definition of "Management Philosophies"	6
Definition of "Management"	8
Definition of "Philosophy"	10
Definition of "NASA Management Philosophies"	12
D. Impact of Management Philosophies on Major NASA Programs	16
Apollo Program Philosophy	18
Saturn I Program Philosophy	19
The Need for the Saturn V Spacecraft and Launch Site Development	21
Development	23
E. Case Studies for Analysis	24
Case Study #1 <u>"All Systems Stage" Explosion</u>	26
Case Study #2 <u>Second Stage-Development Plan Changes</u>	31
Case Study #3 <u>Continuing Second Stage Development Problems</u>	36
Case Study #4 <u>Engine Control Box Problems</u>	40
Case Study #5 <u>Flight Stage Explosion</u>	44
Case Study #6 <u>POGO Problems</u>	48
Case Study #7 <u>Igniter Line Problems</u>	54
Case Study #8 <u>Stress Corrosion Problems</u>	57
Case Study #9 <u>The Delta Project</u>	62
Case Study #10 <u>Applications Technology Satellites</u>	69
Case Study #11 <u>Lunar Orbiter Project</u>	75
F. Conclusion	81
G. Summary	88
H. Enclosure	90
I. References	91

A. Introduction

The space program has generated many "fall out" benefits, which were not an integral part of the initial plans, but which often turned out to be just as important as the scientific results obtained from the research objectives.

One such area is the know-how in the field of management science which was acquired from the Nation's space involvement.

"The Unexpected Payoff of Project Apollo" by Tom Alexander gives a superb summarization:

"The really significant fallout from the strains, traumas, and endless experimentation of Project Apollo has been of a sociological rather than a technological nature: techniques for directing the massed endeavors of scores of thousands of minds in a close-knit, mutually enhanceive combination of government, university, and private industry.

"This is potentially the most powerful tool in man's history. Until now, the only obvious applications for a tool of this sort have seemed limited to something about as massive, imperious, and glamorous as space exploration or war. The question now is whether such techniques can be refashioned and turned to other tasks as well, to tasks as overriding in importance and difficulty as, for example, the management of the earth's complex ecological system, of which man is but one segment."¹

The reader should remember that these lines were written before the first lunar landing had taken place. The author also credited the space program at that time with the tribute that President Kennedy's particular objective had not only been obtained, but was, meanwhile being taken for granted.

1) Tom Alexander, "The Unexpected Payoff of Project Apollo" Fortune Magazine, July 1969 issue, page 114.

This brought about questions like:

"If we can land man on the moon, why can't we eradicate pollution (or cure poverty or rebuild cities)?"²

To this date- five years after the lunar landing-no clear-cut answer to this question has been given. The application of acquired management know-how has been quite successful in some areas, while it has failed in others.^{3,4,5,6,7} It appears that an examination of underlying management philosophies will be in order, and may shed some light on the applicability of space program management to other projects. Different demands on management may call for entirely different approaches, just like production or sales management require methods and procedures different from those for research and development programs.

The importance of enlightened leadership for future programs cannot be underestimated considering the many problem areas that need to be improved: We need programs to control world population, to feed the millions of hungry, to prevent pollution and the depletion of resources, and many others. It becomes apparent that any improvements in the management for these complicated and difficult programs of international scope will contribute to successful program conduct.

- 2) Tom Alexander, "The Unexpected Payoff of Project Apollo" Fortune Magazine, July 1969 issue, page 114.
- 3) J. Gordon Milliken, "Aerospace Management Techniques: Commercial and Governmental Applications," University of Denver, Colo., Nov. 1971-(NTIS-N72-14971)
- 4) Aerospace Management (A General Electric Publication) Volume 5, number 1, 1970, pages 101, 111, 119.
- 5) W.W. Hagerty, et.al. "Research and Education in Management of Large-Scale Technical Programs", Drexel University, Philadelphia, Pa. June 1973.
- 6) J. Von Puttkamer, "Apollo Management," VDI-Zeitschrift Feb. 1973, Volume 115, Number 2, pages 89-99.
- 7) Thomas O. Paine, "The Relevance to Cities of Space Age Management" Address to the National Conference on Public Administration, Miami Beach, Florida, May 20, 1969.

As a first step towards such improvements, this research study will define management philosophies as they applied to mankind's greatest peacetime venture, the exploration and utilization of space. These management philosophies can then be appraised as to their applicability to other major programmatic endeavours, like those listed above.

Accordingly, this study will analyze management approaches and philosophies as they have been applied during the Apollo Program. The study will also determine if these management philosophies apply across the board within NASA, or if there exist already major differences within the Space Agency. A few selected unmanned NASA projects of significance have been studied for this purpose. Similarities in management philosophies of these greatly diverse programs will let it appear likely that they can also be applied to other large undertakings of a research or development nature.

From similarities in management philosophies can be concluded that the subsequently developed policies, methods and procedures will also be useful in the management of these other endeavours. It can also be expected that their intelligent application can assure success of these future programs.

This research study will limit itself strictly to programs which have been completed. The ever-changing methods and procedures of active and "living" programs will not permit the kind of analysis that has to be conducted. Also the judgement on their success will be very difficult to make prior to actual completion of the project. This thinking determined the selection of all case studies used in this report.

B. Background

8

"Management of NASA's Major Projects" by Lee B. James, summarizes research that had investigated methods and procedures that managers had applied to the conduct of their projects. The approaches used to manage these projects were studied and existing NASA management documents were reviewed.

The report was written from the point of view of a project manager in NASA. Considerations in the making of management decisions were discussed. The author used his personal experiences as a manager of one of NASA's major projects to document his observations and experiences in project management. In addition, handbooks, policy guides, instructions, and other documents issued by the NASA Centers, NASA Headquarters, the Air Force, and the Department of Defense were reviewed for reference to pertinent project management data.

In discussing overall management philosophy, it was pointed out that a project manager cannot be passive. Rather, he must be aggressive and on top of all facets of the project. This is done by seizing the initiative at the beginning, with everyone connected with the project. Further, the project

8) Lee B. James, "Management of NASA's Major Projects", Report by the University of Tenn. Space Institute, July 73. (NTIS-74N-10879)

manager is the expert on a given project and proves it by leading, not following.

Another way for a project manager's initiative to be felt is in the development of his project plan as it is both a requirements document and an implementation plan. It is not expected that the project manager write the project plan himself. If he were to do this, other areas needing his attention may be slighted. However, he should decide what is in the plan and review it systematically.

A management information system is considered essential to track and measure progress. Such a system will not succeed in a large project unless it is actively used and understood by the managers.

The following items were discussed under "Management Disciplines": Project Control, Project Planning, Manning, Financial Accounting and Control, Project Scheduling, Configuration Management, Change Control, Interface Control, Systems Engineering, Software, Data Management, Reliability and Quality Assurance, Testing and Test Management, Safety, Logistics, Facilities, Maintainability and Producibility, Specialists, Procurement, Project Records, and Experiments, Each area is reviewed from the standpoint of what a project manager must consider to provide for these functions.

Under a chapter entitled, "Other Important Decisions", are such items as: Human Relations, Project Contractor Relations, Problem Resolution System, Control vs. Innovation, In-House Control, Subcontractor Control, Specifications,

Make-or-Buy Criteria, Packaging and Transporting, What Level to Track and Control, Weight, Performance and Schedule Control, Computer Control, Communications Control, Failure Investigations, Amount of Flight Data, Tracking and Planning Acquisition, Planning for Flight Hardware, Launch Vehicle, Contractor Organizational Phasing, Contractor Key Personnel, Committees, Project Design Reviews, Visits to Contractors, Travel and Overtime, Unsolicited Proposals and Ethics.

The last chapter of the report discusses the Low Cost Approach to Project Management.

In summary, this initial report contains an overview of practically all of the subjects with which a NASA project manager will be confronted. It is primarily intended for use by a newly-appointed manager and to serve as a handbook reference for his many, new, but vitally important functions and decisions.

C. Definition of "Management Philosophies"

Definition of "Management"

An excellent interpretation of the term "management" as it is going to be used in the context of this study was given by the Apollo Program Director⁹ just prior to the accomplishment of the first lunar landing:

"Management of a research and development program is the integration of people into an organized relationship with one another, and providing them the environment, processes, means, and disciplines required to attain a specific objective.

"Size and complexity complicate the management task. Apollo is the largest R & D program undertaken by the United States Government to date. Thirty-five major contractors, more than 4,000 lesser prime and subcontractors, and a large number of Government and Scientific organizations are involved.

"The management challenge has been to organize and orient this complex structure to a singleness of purpose or objective; that of producing the facilities, equipment, procedures, and trained ground and flight crews that are required to extend the boundaries of this country's manned flight operations and to carry out the operations on the surface of the moon for which the system is fundamentally intended."

9) Sam C. Phillips, Lt. General, USAF, Apollo Program Director, address to the National Conference on Public Administration, at Miami Beach, Florida, May 20, 1969, "Management of Large Research and Development Programs."

Another fitting interpretation of "management" is:

"The means by which you specify, gather, and allocate resources to achieve specified objectives. In this process the "manager" seeks and evaluates information, makes decisions, and implements them, usually through other people."¹⁰

It is the purpose of this research study to demonstrate some of the typical pieces of information that the manager has to seek as an input into his decision. These data are not always easy to come by. They are often hidden, and not apparent to the casual observer. It takes much searching and prying to get to the root of the problem; but that is exactly what is required for effective management. A good manager has to know all the tools at his disposal. He has also to be a master craftsman in their use. But, most of all, he has to know the objectives of his project and he has to lead the way towards an effective and prompt realization of the established goals. To emphasize this point, let me also pass on the following observation.¹¹

"There is a tendency to think entirely in terms of procedures, systems, milestone charts, PERT diagrams, reliability systems, configuration management, maintainability groups and other minor paper tools of the systems engineer and manager. We have forgotten that someone must be in control and exercise his judgment, his knowledge, and his understanding to create a system."

- 10) Albert J. Kelley, Dean of The School of Management at Boston College, "Aerospace Management"- and
- 11) Robert A. Frosch, Assistant Secretary of the Navy for R & D, quoted in the same article "Aerospace Management" in *Astronautics and Aeronautics*, August 1970, Volume 8, Number 8, page 46.

This interpretation of "management" reflects also the background and intent of this study. A proficient manager has to display leadership and vitality to make his team meet the objectives of the program plan in a timely and effective manner. Although it is not intended to dwell on the tools of the management trade, it appears necessary at occasions to discuss methods and procedures for a clear demonstration of implemented management philosophies or their derivative policies. This is particularly true for the case studies, which use these tools to arrive at conclusions related to the philosophies behind the management approaches which led to the decisions to take and implement the indicated actions.

Definition of Philosophy

Webster defines the term "philosophy" as follows:

"1a: A love or pursuit of wisdom: a search for the underlying causes and principles of reality: Investigation, Inquiry.
b: a quest for truth through logical reasoning rather than factual observation. c: a critical examination of the grounds for fundamental beliefs and an analysis of the basic concepts employed in the expression of such beliefs. d: a synthesis of learning."¹²

This is one of several Webster definitions which appears particularly suitable for application to our research: We want to find underlying causes and principles which form the basis of all actions taken by the manager; we want to understand the logic and reasoning behind decisions which have been made. As applied to "management philosophies" we want to define a set of basic concepts and principles which will explain to future managers why, where, and how to apply these lessons. A set of examples will be used to conduct this study.

12) Webster's Third New International Dictionary, (1965)
"Philosophy"

Definition of "NASA Management Philosophies"

Top management of any organization must establish a management philosophy to guide the efforts of their people. Such philosophy must be based on assigned roles and missions. The Space Agency was created to recapture the technological leadership from Russian space flight. This led eventually to a presidential assignment to NASA to accomplish in the same decade a manned lunar landing and safe return of the astronauts.

The many organizational and programmatic decisions to fulfill this national desire are superbly summarized in "The National Commitment to Apollo",¹³ which describes the establishment of the Space Agency as well as the many ambitious programs which were tackled immediately.

This background created a management philosophy which permitted accomplishments that have not been equalled by other peacetime ventures. Presidential and congressional support allowed NASA Management to establish a philosophy which was to embrace the intent to become leading in engineering, technology and science. This required the hiring of the best available talent, the merging of these people into dedicated teams performing their difficult tasks with ambition and perseverance and the most advanced equipment at their disposal. Outstanding leadership and the best available management tools were required to perform the job successfully.

13) Robert C. Seamans, Jr., "The National Commitment to Apollo--Action and Reaction"--Astronautics & Aeronautics, August, September, and October 1969, Volume 7, Numbers 8, 9, & 10 (The Minta-Martin Lecture 1968-1969), pages 32 ff., 44 ff., 64 ff.

In a chapter on "Management Philosophy" by the Apollo Program Director¹⁴ the management task has been described as a 3-dimensional matrix that illustrates the relations between the management process, the functional areas in which the process must be exercised and the variables to be controlled.

The management process includes the management activities of defining the requirements baseline, measuring the performance, analyzing & assessing, controlling & directing of changes, and action & feedback. These are equivalent to management interpretations in textbooks which normally include planning, organizing, staffing, controlling, and directing¹⁵. A detailed listing of management tools as they were used in Apollo is shown in the enclosure.

The functional areas of management are listed as Program Planning & Control, Systems Engineering, Reliability Quality Assurance, Testing, and Flight Operations. The Apollo Program Offices in NASA Headquarters and all Field Centers were organized in accord with this breakdown, often referred to as the 5 "Gem Boxes"¹⁶

The three variables have been defined as Scheduling, Costing, and Performance Appraisal (technical). The main task of the Apollo Program Director as well as of all Program Control Offices was to monitor and control these measures of progress, performance, and expenditure.

14) Samuel C. Phillips, Major General USAF, "Management Scheme for Apollo" in Science and Technology Series, Vol. 12, "The Management of Aerospace Programs" (American Astronautical Society), page 193.

15) Harold Koontz and Cyril O'Donnell, "Principles of Management," McGraw-Hill, 1972.

16) Roger E. Bilstein, "The Saturn Management Concept", June 1, 1974, MSFC Publication NASA CR-129029, page 15.

GEM stands for George E. Mueller, the Associate Administrator for Manned Space flight at that time.

Lee B. James expressed in "Management of NASA'S Major Programs" on the third page of his introduction the following thoughts:

"Let us discuss the overall philosophy first. In a nutshell, it is that you cannot "passively" be the manager of any major project. You must be aggressive; you must be on top of all facets of the project."⁸

The NASA Deputy Administrator expressed his thoughts in an article which introduced nine other papers by NASA personnel on the major facets of design, development, and operations in the Apollo program as follows:

"I see one overriding consideration that stands out above all others: Attention to Detail."¹⁷

A former Director of the G.C. Marshall Space Flight Center (MSFC) has expressed in an interview this need by the words "one should leave no stone unturned"¹⁸ to look into all project details.

His successor stated:

"One of the key functions of management is to ask searching questions--the probing questions to locate the weakest links in organizational or procedural systems"¹⁹

He also stressed the importance of communications inside of an organization and also to the outside.

The Apollo Program Director added a systems-oriented viewpoint to these individual philosophies by the statement:

- 8) Lee B. James, "Management of NASA's Major Projects", Ref. 8, Report by the University of Tennessee Space Institute, July 1973.
- 17) George M. Low, NASA Deputy Administrator, "What Made Apollo A Success?" *Astronautics & Aeronautics*, March 1970, page 45.
- 18) Wernher von Braun, Interview with this investigator in summer 1974.
- 19) Eberhard F.M. Rees, *Aerospace Management*, 1967, Vol. 2, Number 2. (A General Electric publication).

"Management of a research and development program is the integration of people into an organized relationship with each other, and providing them the environment, processes, means, and disciplines required to attain a specific objective."⁹

The experienced manager will want to apply proven techniques to accomplish optimum integration of personnel and material. These techniques call initially for the definition of program requirements, which should be built on inputs from the working level. The manager has to assure that no aspect of the project is overlooked. He has to integrate the many individual pieces of data into a meaningful system which will accomplish the defined objectives. His experience and his background should uncover those areas where additional analysis is warranted. His management team and the established management process (see enclosure) will be of tremendous help.

It is a manager's prime responsibility to assure that his actions as well as those of his people will lead to success. A properly implemented, success-oriented management philosophy will certainly enhance efforts towards this goal.

The manager will have to make his management philosophy known to those who must be guided by it. Since "philosophy" in itself is too general a term for implementation, the manager will have to resort to the issuance of "management policies." These in turn will have to be translated into guidelines and instructions to the team. They can be very specific and should clearly express the manager's philosophies. They should be distributed to the entire team for guidance and implementation. All subordinate managers will appraise previously valid policies and applicable procedures. The results of such appraisals will determine if the former tools are still acceptable, and if they can be used "as is", or if they need changes and improvements.

9) Samuel C. Phillips, Apollo Program Director, "Management of Large R & D Programs."

D. Impact of Management Philosophies on Major NASA Programs

In order to study the impact of management philosophies on major NASA Programs it appears proper to select for the initial research the largest and most complex program. This is without doubt the lunar landing which has become known the world over under its program name "Apollo."

This study as well as other literature, sometimes refers to it as the "Apollo/Saturn" or "Saturn/Apollo" program. Such nomenclature gives credit to the selection of the large Saturn Booster, which had a major part in the accomplishment of the lunar mission.

The Apollo/Saturn Program has not yet been surpassed in size or in effort by any subsequent R & D effort, while many of its lessons are being applied to such follow-ons as Skylab, the Space Shuttle, the Space Lab, and even some non-aerospace programs.

In order to test the management lessons from Apollo against other experiences, the last few "case studies" will be taken from selected unmanned NASA Programs. This step will test the conclusions drawn from the Apollo experiences in regard to their validity for other major NASA endeavours.

One of the most important steps in successful management is comprehensive and realistic planning, to include "systems engineering". The task is to identify the way in which the hardware, the software, facilities, people, and procedures will be put together into a complete "system" which must be designed to meet the established objectives in a timely, cost-efficient manner. The systems engineers are also responsible to define all interfaces as well as the technical requirements of the sub-elements that make up the total operating system.

Early in the program--often even before its actual beginning--the system engineers will study many different approaches to accomplish the objectives; they will conduct trade-offs between these alternate solutions based on cost, time, risk, and/or other important criteria; they will select the best method to meet the objectives of the program. They will "leave no stone unturned" to assure that all possible solutions have been appraised in sufficient detail.

Because of the importance of this early phase, it was considered desirable to touch briefly on the thought processes that led to the chosen approaches of the lunar landing and to specific design solutions. There appears to be no better way to demonstrate the effect of management philosophies than to use typical decisions made along the way. Enlightened program management will consider also the history and back-ground of the teams and their individual members. At least a cursory look at the political circumstances and associated sideline facts and figures is needed to relay an actual and factual picture. Only a review of the total situation will assure satisfactory answers to the many questions concerning the acceptance of certain approaches and the rejection of many others.

Some of the used information is not publicly available, since it has been taken from internal NASA files, from correspondence, talks, presentations, and other internal events. However, some of this material will eventually become publicly available through the NASA Historian at NASA Headquarters. 16
A recent publication covers many aspects of Saturn Management. An updated and more detailed version elaborating especially on historical events is in preparation by the same author and should be available in due time.

16) Roger E. Bilstein, "The Saturn Management Concept",
1 June 1974, MSFC-Saturn Publication NASA CR -129029

Apollo Program Philosophy

When President John F. Kennedy announced on May 25, 1961 that a lunar landing would be the focal point of this Nation's space exploration efforts there was no rocket in existence or on the drawing boards that approached the needed boost capability; nor was there a spacecraft under development that could fulfill the requirements of flight to the moon, to land there, and subsequently to return to earth. The only manned spacecraft had just completed a suborbital flight putting the first American in space for just a few minutes. This one-man spacecraft had only very limited capabilities for attitude control and re-entry; it was short in life support capabilities and could not change orbits to any important amount. Tremendous strides had to be made in rocket boost power as well as in spacecraft technology before a lunar landing could be performed.

To accomplish these major feats took support from all management levels, up to and including the President of the U.S. Without his wholehearted support, the landing could not have been completed in that decade. The decision to take such a major step was strongly supported by the political atmosphere at that time, created in part by several recent Russian space accomplishments. It also demanded outstanding leadership within the ranks of the newly organized Space Agency, since the support of just one such major project, possibly to the detriment of others, would certainly create dislocations and manpower problems. But, fortunately, all requisites were there, and the program got under way.^{13,20}

On January 10, 1962, it was publicly announced that NASA would develop a new, much more powerful rocket considerably larger than the eight engine Saturn I, which had been under development by the U.S. Army.

- 13) Robert C. Seamans, Jr., "The National Commitment to Apollo", pages 32 ff.
20) John P. Kushnerick, "The Fight For Spaceflight", Aerospace Management, Sept. 1963.

Saturn I Program Philosophy

The advanced Research Projects Agency (ARPA) had begun on August 15, 1958 a research and development project which eventually evolved into the Saturn Program.²¹ After NASA had resumed program responsibility for Saturn in 1960 it was decided for performance reasons to use liquid hydrogen and liquid oxygen for all upper stages.²² This decision demanded the development of a new engine for this propellant combination.

The proposed launch vehicle program was based on the "modular" or building block concept, which was supposed to provide opportunities to "custom-make" launch vehicles just by selecting the proper combination of stages. The C (for "configuration") -1 vehicle was the simplest. It consisted of the first stage, and two upper stages. The top stage was a modification of the Centaur which was under development and would have been available whenever needed by the Saturn Program. As it turned out, use of this stage was never required, although many studies of this combination were made.

The second stage was designed for propulsion by 6 improved Centaur engines. It was grossly underpowered, and provided only very limited payload capability of the early Saturn I vehicle, but management had decided to proceed with the project to obtain flight experience with hardware and launch crews. However, development of a more powerful

- 21) William R. Lucas, "Political Bugs" *Astronautics & Aeronautics*, October 1972, Volume 10, Number 10, page 44.
22) John L. Sloop, "Looking For the Sweet Combination", *Astronautics & Aeronautics*, October 1972, Volume 10, Number 10, page 52.

upper stage was undertaken as soon as a new high thrust hydrogen engine became available. This improved stage would also later serve as the 3rd stage of the lunar launch vehicle.

But even this thrust increase did not result in a highly efficient booster. The "modular concept" projected, therefore, the use of a more powerful second stage. However, as it turned out there was never a program requirement for such vehicle. The flexibility of the "Modular concept" was never needed, and this apparently highly desirable concept died by the wayside.

The lesson here is that even the most attractive concept philosophies are meaningless unless they meet specific requirements. A mere capability does not necessarily lead to an actual program. Some staff planner had invented the "modular concepts" without down-to-earth requirements from the working-level.

A number of Saturn I and Saturn 1B flights were eventually conducted. Their use was planned in accordance with the management philosophy to place unmanned and later manned command and service modules into earth orbit as quickly as possible. These launches permitted flight testing more than a year ahead of the Saturn V availability. The results provided early flight test experience and contributed greatly to the reliability and dependability of the Saturn booster. The use of the less expensive Saturn I vehicle saved money as an added benefit.

The Need for the Saturn V

More than six months of intensive studies followed President Kennedy's challenge of May 1961 before it was decided on January 25, 1962 that the Saturn V would be the launch vehicle for the lunar landing mission. The needed thrust level would be obtained by clustering of F-1 engines. One of these engines provides the same thrust level as the entire first stage of the S-I launch vehicle. A new second stage would be powered by a cluster of hydrogen engines, while one such engine would power the third stage of the lunar launch vehicle.

The decision on this approach was made on the basis of results from early studies of 3 proposed modes for the lunar landing mission, namely the direct flight to a landing on the moon's surface, the Earth orbital assembly mode, or the Lunar Orbital Rendezvous mode.¹³

In July 1962, it was decided on the basis of cost, schedule, and especially astronaut safety that the lunar orbital rendezvous mode would be used. This decision finally permitted the designers and developers to accurately determine the requirements of the Saturn V launch vehicle.

The magnitude of the payload capability could now be settled on the basis of this decision. Also the volume to accommodate all spacecraft modules within the payload portion of the carrier could now be established with sufficient accuracy to proceed with the launch vehicle design.

13) Robert C. Seamans, Jr., "The National Commitment to Apollo" pages 39 ff.

The results were a three-stage launch vehicle capable of sending almost 50 tons of payload to the moon and/or boosting 125 tons into a low earth orbit. Contracts had been entered already with the Boeing Company for the development of the first stage S-IC, and with North American Aviation, Inc. (Now Rockwell International, Space Division) for the second stage S-II; however, the exact number of engines as well as the tank sizes had not been settled. Such a launch vehicle and its spacecraft would weigh over six million pounds when fuelled. Therefore, at least 7.5 million pounds of take-off thrust would have to be generated by 5 F-1 engines. 23,24

NASA had assumed a certain degree of risk when entering into stage contracts before the design had been frozen. However, in the interest of collapsing lead times for preparation of RFQ's, proposal evaluation, contract negotiations, and other more administrative than technical considerations, management decided that it would be well justified to proceed in spite of many uncertainties as to technical details. It must also be said that the contractor performance judged on the basis of the end results, was superb, although during the course of the development, many problems came up, a few of which will be briefly discussed in the following pages.

This rather detailed account was provided to impress on the reader the need for comprehensive planning, which is so important for the execution of successful programs. Of course, a brief study like this one can only touch on very few typical incidents of decision making.

23) David S. Akens, "Saturn Illustrated Chronology", MSFC, MIR-5, January 20, 1971.

24) David S. Akens, "An Illustrated Chronology of MSFC," MSFC, MIR-10, May 1974.

Spacecraft and Launch Site Development

Detailed attention to planning is a result of established management philosophies. Repeated and thorough reviews at all levels demonstrate the implementation of this philosophy, for which schedules and procedures are well established. The lead role of the manager is apparent.

The just described booster development was paralleled by simultaneous activities related to spacecraft, the launch and test sites, and others. All these program elements were just as critical for the Apollo success as the booster development, which was selected for a more detailed discussion in this study.

It is, however, not the purpose of this management study to relate the entire history of the Apollo Program. Good historical documents exist ^{25,26,27,28,31} and provide excellent information. The management aspects of their development are discussed in previously quoted references 1,9,13,17 and others.

- 25) Wernher von Braun and Frederick I. Ordway III, "A History of Rocketry and Space Travel (New York, 1969).
- 26) Wernher von Braun and Fred Wipple "Moon, Man's Greatest Adventure", Harry N. Abrams, Inc.
- 27) Robert L. Roshott, "An Administrative History of NASA, 1958-1963", NASA SP-4101 (1966).
- 28) Beirne Lay, Jr., "Earthbound Astronauts", 1971 Prentice Hall, Inc.
- 31) "The Kennedy Space Center Story"--U.S. Government Printing Office: 1974-740-742.

The MSFC references 23 and 24 present considerable detail on the overall Apollo program. Several similar publications by other NASA Centers are available for additional detail.

E. Case Studies For Analysis

Extensive planning had preceeded the beginning of the Saturn/Apollo program.²¹ This fact permitted a rather realistic initial cost estimate for the Apollo Program, as well as proper selection and engagement of all resources. An outstanding team of experts could be secured. Replanning continued throughout the duration of the program. These plans had built-in flexibility for "unscheduled" events. A few of these "unscheduled" events have been selected to demonstrate the effect of existing management philosophies.

These "case studies" have been arranged in a more or less historical sequence, although many of these events took place over extended periods of time, and overlapped with others. Alternatives, planned into the systems, solved many problems by straight-forward management decisions. Some of the more intricate problems have been selected for our management analysis. The two most outstanding "unscheduled events" were the Apollo 204 Fire and the Apollo 13 Mishap. Neither of these two events will be discussed in this study, since congressional participation may provide too much bias. These two subjects have been extensively documented.²⁹ The Apollo Fire caused top management to re-assign some personnel within NASA and at the contractor. A review of the existing literature has not shown any gross deviations in the handling of these 2 major mishaps from management measures discussed below.

21) William R. Lucas, "Political Bugs", see page 19.

29) George E. Mueller, "Apollo Actions in Preparation For the Next Manned Flight", *Astronautics & Aeronautics*, August 1967, Volume 5, Number 8, pages 28 ff.

There exist also many congressional records on both events.

The following "Case Studies" will describe the handling of typical "unscheduled events." Early events in the program, such as the All-Systems-Vehicle Explosion, established a pattern for trouble shooting methods and were documented to guide in the solution of future "unscheduled" events. Their managers could use the established policies and procedures to best advantage. Decisive management action always provided effective remedies which kept the program on track. Creation of temporary, trouble-shooting "task teams" was one of the favored approaches.

"There is no substitute for leadership.

Effective organizations develop processes and structures that help management identify critical issues and problems as they evolve, and provide flexible procedures for rapidly applying remedies."¹³

These "case studies" demonstrate the effectiveness of the Apollo Program Management methods and procedures and endorse thereby the established management philosophies during the program control phase. They provide little insight into the initial planning process, which therefore, due to its importance, was described on the preceding pages.

13) Robert C. Seamans, Jr. , "The National Commitment to Apollo --Lessons Learned" (Part II) *Astronautics & Aeronautics*, September 1969, Volume 7, Number 9, page 45.

Case Study #1: "All Systems Stage" Explosion 30

a. BACKGROUND

The fledgeling Saturn/Apollo Program encountered its first major mishap on January 24, 1964, when an "All Systems Stage" exploded during the final phases of a countdown in preparation for a hot firing test. The "All Systems Stage" had been prepared as a prototype of an actual flight stage. As the name indicates, all electrical, electronic and mechanical systems typical of a flight vehicle had been assembled and a hot firing was to demonstrate their operability and performance during engine operation.

The static firing of this stage had originally been scheduled for January 1962; this would have been six months prior to the static firing of first flight stage. However, procurement problems and technical difficulties delayed these initial plans, as well as the need to use this stage to develop hydrogen loading procedures, and insulation and bulkhead repair techniques. Marshall Space Flight Center and Douglas management had expressed a desire to fire the "All-Systems Stage" prior to the forthcoming launch of the first Saturn vehicle with a live second stage to increase statistical confidence in the flight hardware.

b. Description of Event

The "All-Systems Stage" was mounted in a test stand at Douglas Aircraft's Sacramento Test Station in California. Attempts on the two previous days to perform a static firing had been scrubbed due to leaks of a liquid oxygen line in the umbilical disconnect assembly and a non-operating fuel fill and drain valve. A number of other irregularities had also been noticed during these two previous attempts, which led to several corrections based on verbal agreements and engineering judgements: The fuel fill and drain valve had been replaced because

30) K.H. Debus, "Final Report-S-IV All-Systems Stage, Incident January 24, 1964", Internal NASA Report.

of the malfunction on the previous day; a helium shut-off valve had been exchanged and retested. Automatic loading of propellants began and was completed despite a number of technical problems. A few deviations from established handbook procedures were agreed upon, and the terminal portion of the countdown was finally entered. The hot firing test also simulates the first stage burning period during flight by a respective time delay. Several abnormalities occurred during this time, but did not lead to a cut-off signal. Only when the water supply for the flame deflector as well as the steam supply for proper diffuser operations malfunctioned, was automatic cutoff initiated. Almost a minute (approx. 53 seconds) after cut off, the stage exploded with three blasts, resulting in total destruction of the stage and heavy damage to the test stand.

c. Management Actions

Immediately upon learning of the mishap by phone Dr. von Braun made the engineering talents of Marshall Space Flight Center available to project management. Their task was to assemble all the facts and to analyze the causes of the explosion as well as to prepare recommendations for remedial actions. Since the next launch vehicle was poised at the Cape for an early take-off and needed direly all information on this mishap as input the Director of Kennedy Space Center was requested to chair the investigation committee. A key MSFC engineer thoroughly familiar with booster static firing procedures and ground support systems was appointed deputy. Both were supported by other experienced test and design personnel from MSFC. Representatives from NASA Headquarters, other NASA centers, as well as a key contractor spokesman were added to this NASA team.

The formal authority of the team was established in a memo by Dr. von Braun, dated January 29, 1964. This was amplified on February 4, 1964 by additional instructions from NASA's Dr. G. Mueller. The initial contingent of team members arrived at Sacramento on January 26, 1964 at 5:00 a.m. and began

immediately data collection. For this purpose the contractor was requested to make all data, records, personal notes, etc. available for committee review.

The test stand area and all supporting facilities had been impounded immediately upon the incident, as well as all recorded evidence, such as "as-run" procedures, audio tapes, recordings, oscillographs, etc. Instructions had been given to the contractor right after the incident as to the handling of such materials, as well as the general control of the situation.

The gathering and analysis of all available data and other evidence continued until the Committee issued an initial report on February 6, 1964. Fortunately, for a conclusive analysis, much of the damaged hardware was in a condition to allow an orderly process of configuration verification and even functional testing of many components.

The technique used by the committee in pursuing this investigation was to record known facts; formulate questions to be answered by the appropriate contractor personnel and to assign tasks to be performed by contractor test teams. By this method, it was possible to narrow down the analysis of a series of unusual events which had occurred and to identify the pertinent facts. The final report contained all information of the initial issue and in addition, supporting test and investigative data. At the committee's request, the contractor submitted company recommendations for corrective action. These recommendations were reviewed by the committee and supplemented and/or modified based on best judgment. They included improvement of operating effectiveness of the Sacramento Test Center and implementation of remedial actions at other NASA static firing sites.¹⁶

16) Roger E. Bilstein, "The Saturn Management Concept" Saturn Report NASA CR-129029, June 1, 1974, page 32.

d. Cause of Incident

The committee had at their disposal for the determination of the cause of the incident complete data on the "All-Systems Stage," as well as previous Battleship and Flight Stage test data. In addition, essentially all hardware of the stand systems and a substantial portion of the stage controls were available for inspection and testing, because of the short duration of the ensuing hydrogen fire. It was determined that the explosion was caused by the rupture of the stage oxygen tank, which was caused by the failure of the two redundant oxygen vent valves to relieve as intended. The principal cause of the relief valve failure was the abnormal presence of solid oxygen formed because of the abnormally cold temperature.

It should be noted that this incident might not have been destructive if the sequence had not been interrupted by the failure of the steam ejection system to supply the proper vacuum to the engine diffuser, and if the cooling water system had operated satisfactorily.

Twenty-five (25) major and minor abnormalities were noted in addition to those discussed in the previous paragraphs.

e. Conclusion

This mishap was of considerable impact on the entire Saturn I program. Drastic measures were taken to avoid repetition. Many important lessons were learned, which definitely enhanced the future progress of the Saturn/Apollo program in a very positive way. Methods for trouble shooting which were applied to this event established a pattern of investigation, team selection, and remedial actions for all future "unscheduled events."

This case study demonstrates the active management of problem areas by the Program Manager as well as specific actions by his institutional supervisor, who called on his major manpower resources to provide quickly the most effective specialist forces

which will be needed temporarily to clarify the situation. The assignment of this investigation team is to "leave no stone" unturned to uncover all the facts, and to recommend remedies to prevent re-occurrence of similar mishaps.

This first case study also demonstrates the function of the investigating committee as a special "task team". This operating method was many times successfully employed throughout the program. Rapid establishment of such teams when needed, clear assignment of specific and time-limited tasks and quick implementation of recommendations for remedial measures are typical management functions which will determine a manager's effectiveness and control over his program.

Another interesting fact is provided by extensive evaluation of this accident in regard to the effect of an explosion of pre-mixed propellants. The results of this study are documented in a special NASA report.³²

32) J.B. Gayle, NASA TN D-563, "Investigation of S-IV All Systems Vehicle Explosion", September 1964.

Case Study #2: Second Stage- Development Plan Changes

a. Description of the Situation^{23,24}

MSFC management had recognized early in Saturn program planning that the development of the second stage for the lunar launch vehicle would pose one of the major problems. Difficulties were foreseen and did occur in such areas as material selection, welding procedures, choice of insulation and its installation, structural demands and others. All problems were amplified by the first large-scale use of the supercold propellant liquid hydrogen.

Initial plans had therefore provided for one flight with a "dummy" (nonpropelled) second stage. Such a launch would give the contractor a little more time for the development of a "live" flight stage. It also would save money in case critical flight anomalies occurred during the propulsive phase of the first stage, which was simultaneously undergoing its first flight mission in the same launch.

Triggered by criticism that NASA had to undergo in connection with a series of Saturn-I flights with dummy upper stages, the Associate Administrator for Manned Space Flight decided late in 1963 to apply an "all-up" test philosophy to the Saturn-V development. Such "all-up" testing provided for the use of "live," i.e. propulsive upper stages from the beginning, and excludes accordingly the use of "dummy" stages. Such daring approach had been made possible by the tremendous progress which had occurred in rocketry, as demonstrated by these events: Approximately a month after the "all up" decision, the first Saturn I with a live upper stage orbited a record payload of 37,900 pounds. The first stage of this launch vehicle had proven itself in this

23) David S. Akens, "Saturn Illustrated Chronology", MSFC, MHR-5, January 20, 1971.

24) David S. Akens, "An Illustrated Chronology of MSFC," MSFC, MHR-10, May 1974.

as well as in all previous flights. Especially the much debated question as to the suitability and viability of the "cluster concept" had been demonstrated by this series of successful flights, which was now considered safe for use in the first and second stages of the Saturn V. The decision to use liquid hydrogen as fuel for all upper Saturn stages had created the problem of non-availability of upper-stage systems for early flights. The decision alternatives for management were to either fly with "dummy" upper stages or to postpone flight-testing until advanced propulsion systems had become available. The latter approach would not have provided any flight data at the time when the "all-up" testing decision was made. Since early Saturn management had foreseen such timing problems, it had decided to adopt the approach of flying dummy upper stages in order to get the large booster program under way and to obtain preliminary flight data. The availability of positive test information from these early flights puts Apollo Program management now in a position to wait for the availability of the second stage, and to forego the use of a "dummy" second stage. Use of "dummies" for the third stage had never been considered, since this stage was being flown on the Saturn-1B launch vehicle, thereby demonstrating its flightworthiness prior to its use for the lunar mission.

b. Implementation of the "All-Up" Approach

The decision for "all-up" flight testing caused a review and re-alignment of the entire development hardware of the second stage. The "dummy" stage, which was already under construction, was converted into a flight unit.

An already scheduled non flight stage for test firings (S-II-T) took on increased importance. Addition of a new test element to the development plan was considered necessary to demonstrate the acceptability of one of the most critical design features of the second stage, the "common bulkhead" separating the two propellants

in the tankage. This unit became subsequently known as the "CBTT" Common Bulkhead Test Tank.

Parallel to these efforts a "Battleship" unit was being prepared for hot firings to study engine operations, combustion exhaust gas interactions, shut-off procedures, etc. This "Battleship" had an entirely different tank configuration, consisting of 2 individual tanks for the 2 propellants; therefore, it did not have to cope with the common bulkhead problem. This unit became ready for testing in mid-1965, and was gradually increasing engine burn times after a series of short duration "ignition tests" had been run. These same tests were repeated later on with flight-type engines of the latest production run.

The need for ample test hardware was emphasized by the recent explosion (early 1964) of the "All-Systems" test vehicle in Sacramento, California. (See Case Study #1). This "All-Systems-Vehicle" had been used extensively in an almost completed test series. The incident demonstrated to management the vulnerability of all hardware used in test firings and the need for back-up systems. Contractual realignments considered this experience in the changed requirements.

c. A Special Test Fixture

The actual construction of this new CBTT fixture for testing of the common bulkhead design under liquid hydrogen temperature conditions had to wait for the design freeze of the second stage, since the CBTT was a shortened version of the full-length S-II tankage. Parallel to the design and construction of the stage, a special test facility had to be built for structural tests with propellants, applying the simulated thrust of

the 5 engines to the thrust structure as well as internal tank loads simulating flight acceleration. Material selection, welding techniques, and all manufacturing processes were duplicated from the regular production methods for the flight hardware. This duplication should assure that all obtained test data would be representative of the actual flight items themselves.

Cryogenic testing with this unit demonstrated the integrity of the common bulkhead design, the forward skirt, and the tank wall joints. The initially planned test program for the CBTT was completed in late 1965.

The CBTT found further use in 1966 when management directed that this unit should be used to test structural repair methods, primarily the bolted doublers being used to reinforce certain areas of the hydrogen tank. In mid-September, this direction was extended to include the installation and the testing of the redesigned feedline elbows of the hydrogen lines. In one of these tests the CBTT was finally destroyed when the hydrogen tank ruptured during a pressure test to certify some of these design features of these new elements. The final failure occurred in the area around a recirculation pump boss, which might have been overstressed during one or more of the many special runs made with the unit.

d. Management Appraisal

The CBTT had well served its original purpose and had provided extended service for an additional set of runs for ancillary components attached to the tankage. Management decided not to replace the CBTT, as all primary testing had been completed. It had been planned prior to the failure to continue use of the CBTT for feedline elbow testing. It was determined that these tests could be continued with the "Battleship" and other test facilities.

This rather simple CBTT unit provided a wealth of data for structural and general test engineers and made thereby a major contribution to the success of the launch vehicle program. Its rather late inclusion in the development plan attests to the flexibility that management displayed at all times. The introduction of the "all-up" test philosophy is another demonstration of management flexibility. This introduction generated exhaustive discussions on its merits, but the final success of the lunar program as well as the cost savings by deletion of one complete Saturn flight have by now amply proven the correctness of this decision. Flexibility of program planning is furthermore demonstrated by the availability of the "Battleship" at the critical times when mishaps occurred with other test or flight hardware. An early beginning of test firings can uncover hidden problems and contributes to the implementation of the groundrule to "leave no stone unturned." The extensive use of the CBTT is another demonstration of the same philosophy. It is the manager's task to encourage his team to make such recommendations from the working level. He has to propose such program elements to higher level management, who may often be inclined to save expenditures, or costly efforts, and who have to be convinced of the need to proceed as proposed.

Case Study #3: Continuing Second Stage Development Problems

a. Description of the Situation^{23,24}

Some of the early development problems with the Second Stage were sketched in the previous case study. Due to the described development plan changes, the availability of a test stage had become the pacing item. Such a stage was supposed to demonstrate by static firings the flightworthiness of the second stage. For this purpose it was to be built according to the latest design of a flight article. It was given the name S-II-T.

When such test article finally became available, damage had just occurred to a structural test stage, which was scheduled for subsequent use in MSFC's dynamic test facility. Due to the overriding urgency of dynamic Saturn V testing, the MSFC Stage Manager had to request the contractor to study a program plan which would provide for the use of the S-II-T for the dynamic facility. Other ground rules of this request were that any S-II-T modifications would be done at the test site; a flight stage would be used to activate the Flight Acceptance Test Stand rather than the S-II-T stage; no test stand constraints would be imposed on the flight stage of the first Saturn flight. Battleship Test Program reorientation would be accomplished in accordance with the recommendations of the MSFC assignment team currently at the contractor site.

The presence of this special task team at the contractor site assisted the stage manager considerably in the timely solution of the problems.

- 23) David S. Akens, "Saturn Illustrated Chronology", MSFC, MHR-5, January 20, 1971.
24) David S. Akens, "An Illustrated Chronology of MSFC," MSFC, MHR-10, May 1974.

This request emphasized the fact that many questions in regard to development problems were still wide open and had to be solved before the stage would be acceptable for a Saturn V flight. Continuing schedule corrections and adjustments became necessary to make up for encountered slippages and to prevent bad delays in the Saturn V program. This situation led top echelon contractor management to assign a top-notch, well-seasoned stage manager, and to the simultaneous transfer of 300 engineering personnel to office trailers at the manufacturing site at Seal Beach, California, the final assembly site of all stage production and assembly activities. Such a drastic step appeared necessary to assure faster corrective actions by design changes in response to manufacturing difficulties. This need for closer ties finally necessitated the relocation of all engineering activities into a new plant to be constructed at Seal Beach.

The S-II-T stage could finally be filled for the first time with actual propellants after repair of minor discrepancies. The first short duration (15 sec.) firing took place with only small anomalies. A successful 150-second test followed, and a full-duration test of more than 350 seconds duration was made on May 20, 1966.

b. Occurrence of Test Anomaly

Maintenance testing after the successful run in preparation of follow-on firings led to destruction of the S-II-T Stage on May 28, 1966. The hydrogen tank had been pressurized with helium gas in an effort to isolate leakages that had caused a fire around a recirculation pump. There was fortunately no liquid hydrogen in the tank when it ruptured. The failure resulted from propagation of a small fracture in a raised boss. This happened at a pressure which was considerably lower than the ultimate design value.

This incident led to inspection of all stages with the intent to discover similar "cracks."

Especially hydrogen tanks were checked because of the temperature problems. Other cracks were found, and an intensive investigation was started to determine when these had occurred, and under what specific conditions. This activity led to an intensive follow-on effort of "fracture mechanics" investigations, which it would lead too far to discuss in any detail here at this time.

c. Management Measures

The MSFC Stage manager requested the contractor to propose a recovery plan. Those test objectives which had still to be accomplished were to be assigned to Battleship testing as well as to the first two flight stage acceptance runs. This was a very unusual step for MSFC test philosophies, and is indicative of the predicament

The recovery plan was approved in July 1966. It removed previously existing time reserves completely, and extended the dwell times of the first two flight stages at the Mississippi Test Facility to permit the additional test activities to satisfy the remaining test requirements.

This accident also led to the approval of a "Confidence Improvement Program" which was based on work by a "Structural Assessment Team", which consisted of MSFC specialists in the areas of design, materials, manufacturing, inspection, testing, and other vital areas.

The efforts of this rather small and unofficial "Assessment Team" led finally to the highly effective "Tiger Team", which was dispatched in early January 1967. Their mission was to improve the time cycle of design approvals, to agree on remedial actions for discrepancies, new test plans and inspection methods, and to handle many things which just wasted too much time by routing through routine approval channels. MSFC personnel were assigned to these duties on a temporary, but extended time basis. The Deputy Director of MSFC spent a considerable amount of time himself on these functions. This fact supported the actions of the "Tiger Team" tremendously. Such high level support assured that also the new contractor

management was lending full support to these "Tiger Team" tasks. This was apparently the only way to expedite these often drastic, and always cumbersome changes and modifications.

d. Conclusions

The final success of the Apollo Program, as well as the excellent flight performance of all second stages speaks well for the implemented remedies. This action turned out as real teamwork. The endeavour to be of greatest possible benefit to the program was uppermost in everyone's mind. It was often difficult to distinguish between contractor personnel and between the Civil Service people. They had all the same goal, and both parties were doing their utmost to bring the stage development to the desirable end. After initial difficulties it turned out to be an outstanding example of true team spirit and cooperation.

This case study shows that often even the pre-planned contingencies will not suffice. This then are the instances when the manager has to take the lead and exert special efforts to arrive at acceptable solutions. The events of this case study led to superb team-work which solved a most difficult situation. Management succeeded to instill the necessary spirit to overcome one of the biggest hurdles. Such special task teams became almost a way of life for many critical events throughout the Apollo program.

Case Study #4: Engine Control Box Problems

a. Description of Situation

The hydrogen fueled engines of the Saturn Upper Stages created a new set of requirements which had not been encountered before: All engine components had to remain functional during extended space operations at low temperatures (-130°C); They had to be turned on for operation in an accurately specified sequence from an electric controller, called "Electrical Control Assembly-ECA". The engines had to be "man-rated".

The initial design concept of the ECA was based on the use of high-reliability components as developed for the Air Force Minuteman program, but used otherwise standard design and test specifications applied for ECA manufacture. The assembled ECA's were functionally tested at -130°C and given a vibration shake-down test. The unaccessibility of components in the potted assemblies caused high fabrication cost, which led to a series of redesigns. Printed wiring boards, improved soldering, and more accurate ignition exciters and timers were combined with the requirement that the vendor had to do the qualification.

Many apparently minor, but very significant improvements in component selection, circuit board construction and soldering techniques, addition of heat sinks and better assembly methods finally improved the ECA sufficiently for manned flight. Fortunately, all ECA anomalies could be identified during checkout, static firing, or special ground testing, and never occurred during Saturn flights.

b. Typical Anomalies

An ECA failure during launch site checkout in June 1966 focussed top level management attention on the situation. The cause of the failure was a fractured solder joint. An inordinately high number of defective timers began to appear in ECA acceptance testing by late 1966.

During a hot engine firing in February 1967 at the Arnold Engineering Development Center (AEDC) premature cutoff was given. Failure analysis revealed that the malfunction was caused by a piece of loose safety wire within the ECA assembly.

c. Management Remedies

As a result of the failure at AEDC, management decided to return all flight ECA's to the engine contractor for internal inspection. This measure led to a complete revamping of the manufacturing assembly area, specific contamination prevention measures and personnel awareness training. Special assembly booths were established. These were not located in the board soldering area to preclude inadvertent introduction of wire ends into the assemblies. Scrap-retention pliers and strict safety-wire "tag-end" accountability processes were invoked. Detailed inspection steps for verifying cleanliness of the ECA prior to installation of the ECA enclosure were documented and added to assembly operations requirements.

In order to solve the many other soldering problems, a special procedure was imposed on all ECA assemblies: Critical solder joints were inspected at 20-fold magnification for cracks and stress prior to and after thermal exposure to -200°F. This thermal "culling" process was retained until different requirements obviated this test rather late in ECA production.

Failure analysis and test programs resulted in improved plating and terminal dimensions for solder joints and led to a controlled laminating process for the boards, which substantially reduced rejections.

Of considerable program significance was the complete renovation and upgrading of the entire soldering operation at all contractor plants. A thorough review of specifications, training, equipment, and techniques brought about a "clean-up" campaign. New process specifications and training manuals were published; personnel were re-trained; equipment was standardized, upgraded and calibrated; soldering criteria and inspection records were invoked.

Soldering quality on ECA;s and many other items of flight hardware has been maintained since at highest workmanship levels.

d. Appraisal of Management Measures

The ECA became a management concern as a potential weak link in the Saturn launch vehicle about mid-1966.

The inherent lack of design redundancy might prevent the engine to start. MSFC management considered several approaches to solve this critical problem, including a completely new redundant design. However, since this system could not be built and tested in time for early manned missions, it was rejected. Accordingly, management decided to monitor test results of the new ECA design very closely to insure attainment of an acceptable level of reliability or risk. It was decided to work the problem real hard and to eliminate all potential failures by steps for additional tightening of manufacturing processes and quality control, retro-fitting and recycling from the field. Since the sequence timers were the most critical single point failure item in the ECA, redundant timers were eventually introduced on late Saturn flight vehicles.

In retrospect, it appears that these measures of great detail attention were effective in obtaining satisfactory flight reliability, as indicated by the fact that no flight failures ever occurred. A requirement from the very beginning for a redundant system would have eliminated much of the concern, although it is assumed that failures would have had about the same amount of management attention regardless of the redundancy. One of the most predominant factors in the way the design evolved probably was influenced by the fact that the engine contractor had only a limited amount of expertise in the electronics field which may have accounted for the necessity of several designs.

The approach for the Shuttle Engine controller will reflect the lessons learned from the above indicated problems. Requirements for full redundancy and no single

point failure modes were established as an engine control requirement. Also a well experienced subcontractor in the electronics field was selected to handle the design and production of the control system on the engine.

This case study is a typical demonstration of action oriented monitoring and controlling by the manager even down to the component level of a subassembly. It also shows clearly the impact that remedial measures can have on other associated areas of the project. The manager assures by suitable reviews "that no stone is left unturned" and that all aspects of the failures as well as the proposed improvements are examined in depth. All actions and implemented remedies demonstrate also a typical team operation. A major rewrite of handbooks and specifications was implemented to assure that future projects will obtain the benefits from the lessons learned.

Many of these remedial actions were taken by lower-level managers and technicians. However, the final and most drastic measures were directives from top management. This indicates the depth of penetration which often becomes necessary for the successfully managed program. The initial "visibility" for top management had been poor, but became entirely adequate after the problem had been recognized. The implemented remedies made a major contribution to improved reliability of all ongoing and future NASA programs.

Case Study #5: Flight Stage Explosion³³

Description of Event

On January 20, 1967, a hot firing of a third stage flight unit was to demonstrate proper functioning of all electric and pneumatic systems.

Although all monitored systems operated nominally according to the instruments and records, the stage exploded 11 seconds before simulated liftoff, i.e. well prior to its own ignition command.

The explosion destroyed the flight stage completely and damaged the Test Facility severely. Fortunately, due to the built-in safety-provisions, no personnel injury occurred. However, the fact that this was the second explosion of a third Stage on a Douglas Sacramento Test stand focussed special attention on it.

Management Action

Immediately upon receiving the report on the explosion, the Director of MSFC as the responsible NASA Center, established a Board of Inquiry under the director of the Kennedy Space Center as chairman. The following committees were formed to support the investigation:

- a) Data Protection and Inventory
- b) Documentation Review
- c) Crew Procedure, Operation, and Safety
- d) Personnel Interviews
- e) Damage Assessment and Mapping
- f) Cause Isolation Investigation
- g) Photographs

33) Most facts of this summary have been abstracted from MA001-005-211, in MSFC SATURN V semi-annual progress report Jan.1, '67-June 30, 1967.

The contractor established also its own investigative group, especially geared to replanning of follow-on activities, the immediate implementation of remedial measures and support of the NASA activities.

Determination Of Failure Cause.

Preliminary debris analysis had already indicated that apparently one of the eight high pressure helium spheres which are mounted on the thrust structure of the stage had failed. For weight reasons these spheres are constructed from titanium and are just prior to launch pressurized to more than 3000 psia. The helium gas has to repressurize the liquid oxygen for restart of the engine in orbit. It was subsequently determined that the subcontractor had inadvertently welded a few spheres with improper welding rods (pure Titanium instead of a titanium alloy). After thorough examination of all facts, the Board of Inquiry concluded that this improper production method was the cause for the rupture of the helium pressure vessel. Otherwise, the investigation showed that test planning and execution had been done in a professional manner, and that all stage, test, and ground support systems performed in accordance with established specifications up to the moment of the explosion. The Board determined that the operating personnel could not have predicted or prevented the incident on the basis of the displayed and available information. Apparently all lessons learned from the previous explosion had been applied and proper steps had been implemented.

Implementation of Remedial Steps

As a result of the explosion, a "Helium Bottle Investigation Program" was initiated to remedy the shortcomings encountered during the acceptance test. In this program, the contractor was required to conduct a series of burst tests with weld-discrepant and with non-discrepant bottles. These tests with discrepant bottles indicated after burst tests to failure the formation of titanium hydrides in the micro-structure of the pure welds.

It is known that massive hydride precipitates cause weakness in the metal structure.

Even though the evidence was not entirely conclusive, SATURN program management decided to replace all bottles which had been welded with pure titanium wire. MSFC's traceability records made this readily possible. Fortunately, this affected only titanium bottles which had been fabricated with filler welds due to the wall thickness of the wall material. The "cold helium" bottles, which store the helium inside the stage's liquid hydrogen tank - and are therefore, much less accessible - do not have filler welds and were therefore not affected by the replacement or re-checking program.

As a measure of additional assurance, all existing ambient helium storage bottles were subjected to eddy current testing to determine the soundness of their welds.

The acceptance Test Stand had been extensively damaged from the explosion, as was documented in considerable detail by the Board of Inquiry. The stage manager approved a stand reactivation program, consisting of several phases.

The actual refurbishment of the stand began during the last full week in May, 1967. The contractor undertook with his own personnel the refurbishment of all ground support and test equipment. Some items could be restored to a serviceable operating condition; much destroyed equipment had to be replaced. The stand was back in operation by late 1967.

The loss of this stage caused stage management to implement a re-allocations and/or redesignation program for all affected stages.

Conclusion

After thorough review of all remedial measures to be implemented as well as extensive rescheduling plans, Apollo/SATURN Program management announced that this incident in itself would neither delay the first manned Apollo flight nor,

the lunar landing. This announcement could be made although many ongoing activities connected with the launch vehicle development were impacted to a considerable degree. One fact that aided greatly was the "traceability" of components and materials, which showed that only very few pressure vessels were produced with the improper welding techniques. The helium spheres in launch vehicle SA-204 were, for example, not affected; however, it was concluded to inspect these pressure vessels anyway prior to launch.

The lesson from this mishap is that traceability of components, and even their manufacturing process will be very helpful in case of accidents. It may during these critical times well pay for the added expense for such "traceability" records. In any case, the high degree of "visibility" and confidence that is existing for decision-making is definitely a strong asset. It certainly enabled the manager in this instance to issue firm directives in time for the continuation of the program. The cost of "traceability" records must be weighed against the possibility of failures and major mishaps and their potential impact on the program. It appears that in a difficult and nationally prestigious program with firm schedules like in Saturn/Apollo, the benefits are well worth the cost.

These case studies also demonstrate how responsibilities assigned to task groups (Board of Inquiry) can assist the manager in a quick and efficient manner. This method provides great flexibility in management and organizational arrangements.

Case Study #6: POGO Problems

a. Summary of the Problem

The second prototype of a lunar launch vehicle Saturn AS-502 performed an apparently successful flight in April 1968. Only post-flight evaluation showed as one of the critical anomalies of this flight a pronounced "Pogo"-effect, a dynamically unstable longitudinal oscillation of the launch vehicle propulsion system, produced by coupling of the vibrations generated by the rocket engine combustion with the inherent frequencies of the propellant feed system, and the vehicle structure. Such energy coupling is undesirable for the structural elements and unacceptable to the crew if excessive. It has been compared with the annoying feedback squeal encountered when the microphone and the loud speaker of a public address system are coupled.⁹

No such Pogo effect had been observed on the previous flight prototype vehicle Saturn AS-501, which was the very first launch of a Saturn V and had taken place in November of the preceeding year. Extensive analytical and experimental studies had been conducted prior to flight and static testing of the Saturn V system. All results promised that this detrimental event would not occur in Saturn V flights, although the limits of safety were not so great that this possibility could not be ruled out entirely. However, the engineering team felt pretty confident about the results of the theoretical analyses when Pogo occurred neither in the first launch nor in the many static firings of the Booster. All static firings were conducted under simulated conditions as closely as they could be obtained in these static firing tests.

9) See reference # 9. Speech by Lt. Gen. Sam C. Phillips, USAF, Apollo Program Director at Miami Beach, Fla. on May 20, 1969 on "Management of Large Research and Development Programs".

This feeling of security was amplified by the situation that no Pogo effect had ever occurred in any of the previous Redstone, Jupiter, or Saturn I and Saturn IB flights. The design principles of the basic combustion systems, the propellants, and the propellant feed systems were very similar in concepts. Therefore, a problem of this type had really not been expected, although other programs had been haunted by Pogo effects to considerable degree.

When this anomaly occurred on AS-502, immediate remedies became a matter of urgency for the entire Agency, especially the Saturn Booster development Agency, the MSFC, which was reaffirmed as being responsible for the lead by the Apollo Program Director.

To prevent the occurrence of Pogo in time for the third Saturn V flight, which was then scheduled for December of that same year, became of prime importance since it had been tentatively considered to make it a manned flight. This could be accomplished only when all indications of the implemented countermeasures did clearly indicate that the Pogo problem had been overcome. The problem was one of magnitude, since the savings accomplished by one less flight test vehicle amounted to several hundred million dollars. Attainment of the Apollo goal to accomplish the lunar landing during the decade would be enhanced greatly, if the solution to the problem could be accomplished in time for the next flight. Otherwise, the larger number of launch vehicles required to meet the predicted Apollo time schedule would be gravely endangered.

b. Management Approach to a Solution

The Apollo Program Director summarized the implemented action as follows⁹:

. . . "As a consequence, the Apollo team took immediate action. The Marshall Space Flight Center was reaffirmed as

9) Ibid, page 7

responsible for the lead, in a total vehicle sense, in the resolution of the problem. The Marshall POGO working group was reactivated. It was made up of senior people from Marshall, the Manned Spacecraft Center, the Langley Research Center and the first stage contractor; contractors, who in past years had experienced this problem on other vehicles, like Titan, were brought in. To insure good liaison between centers, representatives were exchanged between Houston and Huntsville. An astronaut was assigned full time to the working group, as was my Deputy Director. A total of about 700 professional people from Government and industry contributed to the effort".

With these guidelines and instructions from NASA Headquarters, the Deputy Director of MSFC, took it upon himself to head this effort. He got all necessary resources assigned to a task which would definitely tax the existing organization greatly, but which needed to be done if major consequences to the Saturn-Apollo program were to be avoided.

The "Pogo Working Group" was to coordinate all associated activities, to assure that all vital areas are being studied to coordinate intermediate results, and to arrive at the final recommendations to be presented to the Apollo program manager for his approval. The working group consisted mostly of MSFC and other NASA personnel, who were delegated to this job on a temporary basis until an acceptable solution had been found. Their activities were supported by a sizeable contractor team, who were assigned specific tasks for quick and timely resolution. These contractor teams called on the Aerospace Corporation, The Boing Company, The Martin-Marietta Corporation, and TRW-Systems.

The tasks assigned to the working group called for a sizable effort and included to: 1) understand the reasons for this surprising event, to 2) propose suitable countermeasures, to 3) test these measures for their efficiency, and to 4) select the best suited approach, to 5) build and

test the necessary hardware, to 6) install it in the next flight vehicle without any major change in the flight schedule.

Detailed reviews were held at the contractors plants at the stage and engine test sites, at the MSFC Field Center, and in NASA-Headquarters. Many other top NASA leaders paid full attention to the ongoing activities, monitored theoretical results, test data, conclusions, and the final recommendations. In the final review, the Apollo Program Director concluded, that the proposed measures would provide a timely and acceptable solution and the necessary safety margin to man the next vehicle as well as to eventually assure a safe journey to a moon landing. He said about these reviews himself the following: "My primary emphasis during this time period was on frequent review of progress. Included were a review of Apollo 6 initial results, five technical working group reviews and regular status reviews by telecon network. For the telecon network reviews the three manned space flight centers and my Washington Program Office are tied together by telephone. The information under discussion is displayed on screens at all four locations. This procedure has proved to be a very effective way of communicating the total wealth of information being developed in a dynamic way to all interested parties".

The technical solution to the POGO problem was fortunately rather simple. It was found by the many parallel efforts that the already existing 5 pre valves in the oxidizer lines leading to the 5 F-1 engines of the Saturn's V first stage could be utilized to charge gaseous helium onto the system. An annular cavity in the housing of this pre valve could be used for this purpose. The presence of the gaseous helium provides sufficient "springiness" to the oxidizer feed system that it will decouple the effect of the engine's combustion vibrations on the longitudinal excitations of the structure. It was fortunate that the pre valves had been included in the Saturn V first stage, although they had no specific flight function. They

had only been provided for ground testing so that in case of engine malfunction, the main oxydizer flow could be shut off. This "prevalve accumulator" (PVA) became the key element in reducing suction line frequency, and thereby decoupling the engine-structures oscillations. Helium could be supplied during the flight from an existing on-board source, and the required amount was rather nominal. The PVA operational sequence begins before lift-off at about 10 minutes before launch, so that the PVA cavities are filled with helium gas by the time of oxidizer tank pressurization. At that moment, they are slightly compressed, but still sufficiently filled with gaseous helium to accomplish the vital job of frequency reduction during flight. A much more detailed description of the system with diagrams and a historical background is given in reference.

c. Final Management Measures

As a great surprise to many engineers and in spite of extensive analyses and verifying test results prior to actual flights, the POGO anomaly did occur on the second launch of the Saturn/Apollo launch vehicle. The entire Apollo team was called into action to solve the problem. It was fortunate that a quick solution could be found based on the extensive analysis which had taken place earlier.

Management saw to it that necessary manpower resources were made available on short notice and were organized as "task teams"; they had the wholehearted support of all management levels. Overtime, travel, shifting of less important endeavors, addition of supporting contracts, and other measures could be implemented on shortest notice, quite contrary to the usual civil service procedures and regulations.

Potential remedies were discussed on the highest levels of management, and were not merely left to the discretion of the working level people and their resources. The final recommendations were presented to top-management for review,

detailed discussion of possible pitfalls, and for final acceptance.

Fortunately, all these steps could be taken in time and were successful. The next Saturn flight could be manned and carried Commander Frank Borman and his crew to a circumlunar mission during Christmas of that same year.

Even after this successful flight had shown that the POGO problem had principally been solved, all subsequent vehicles were continued to be monitored closely as to combustion vibrations and structural response characteristics. These measures were extended to the vehicles of the Skylab and Apollo-SOYUZ Programs.

Such detailed flight data combined with ground test information led the Saturn Program Manager to recommend shut-down of the center engine in the second stage before final cut-off in order to overcome a slight POGO indication which had shown up in the flight records of Apollo 8 and Apollo 9 missions. After thorough evaluation of all evidence, the Apollo Program Director accepted the recommendation and decided to switch off the center engine about 80 seconds early.

A captive firing test of an identical stage was successfully terminated early without adverse affects and supported the decision. To compensate for the thrust loss of the fifth engine the Saturn V guidance system was reprogrammed to steer in accordance with the "engine-out" plan, and to burn the 4 outboard engines about 15 sec. longer.

d. Conclusion³⁴

The POGO problem was just one of many similar "unscheduled events" which happened during the conduct of the Apollo program. Thorough analysis of available data, an educated appraisal of their significance by experienced teams, and decisive management action to overcome the situation made it possible that the lunar landing could be accomplished during the next summer, well within the predicted schedule.

34) Erich E. Goerner, "Lox Prevalve to Prevent Pogo Effect on Saturn 5", Space/Aeronautics, December 1968, Volume 50, Number 7, page 72 ff.

Case Study #7. Igniter line Problems.

a. Description of Event.

The last flight of an unmanned Saturn vehicle was cursed with another serious malfunction besides the POGO problem which was just discussed in the previous case study. It took much engineering analysis of the flight records to trace the problem to the sparkplug igniter line for the main engines, which provide propulsion for the second the third stages of the lunar launch vehicle. Both stages use liquid hydrogen as fuel, which caused a part of the encountered difficulties. Details of the events of the flight connected with this problem have been described in a contractor report, which has been quoted in available open literature.²⁸ The initial indications from the flight records provided just the information that the environment around the augmented spark-plug igniter (ASI) line was excessively and unexplainably cold. No reason for such conditions could be immediately determined from the other flight data.

Fortunately for the Apollo program, the booster controls could compensate for the erratic operation of the propulsion system, mostly due to the POGO effect, but also affected by this malfunction. The resiliency of the Saturn System could successfully put the third stage and the unmanned spacecraft prototype into a low earth orbit, as planned for this specific unmanned mission. This fact aided greatly in isolating the causes of this problem.

28) Beirne Lay, Jr, "Earthbound Astronauts", page 140, (1971). Prentice-Hall, Inc.

b. Determination of Failure Cause

Since similarly low temperatures had never been recorded in previous flights or ground testing, management decided to establish a special task team to track down the exact reason for these temperature conditions, to support any conclusions by ground test demonstrations, and to propose remedial solutions.

In a seven-day-a-week, around-the-clock effort, the problem was solved in a timely manner by assigning all available resources to these activities, and to declare them as having top priority. Contractor and Government engineers went over all drawings and interface documents. Quality control people studied workmanship and acceptability of all involved parts and components, especially those located close to the ASI line, where the low temperatures had been recorded.

Failure analysis indicated that a ruptured ASI line could cause the observed drop in temperatures. However, in spite of an endless number of test firings, the ASI line failure could not be demonstrated during these tests, although flow rates were increased to very abnormal values, and gaseous nitrogen was forced into the propellant flow to stimulate vibrations. Two teams were working on the problems. One team represented the second stage of the Saturn vehicle, and used five engines in all tests, while the other team simulated the third stage operation, and run only the one engine representative of that stage. Although the ASI line was found to have operating points sensitive to certain vibration frequencies, it could not be made to fail.

Only by meticulous duplication of space conditions in a very elaborate test fixture and operation in vacuum could the ASI line failures finally be duplicated. Under these very special conditions, eight of the tested ASI lines failed within less than 100 seconds. The flight failure had been duplicated by attention to infinite detail, and very careful and painstaking duplication of space conditions. Simulation to such a degree is normally not required to obtain representative

test data. Additional testing found that at ground pressure, the ambient air liquefied and was hiding the trouble. This protection of the line bellows by the frost formation does not occur in the greater altitudes with very low ambient pressures, where the engine is reignited after a lengthy coast period. It took the engineers only 30 days to accomplish the many steps summarized above. This was only possible by strong support by all management levels.

c. Remedial Actions

Fortunately, for a timely continuation of the Apollo program, the "fix" was very simple and could be accomplished quickly. It was just necessary to eliminate the use of bellows altogether, and to use an alternate routing of the ASI line to its designation by means of a few loops instead of the bellows. This solution to the problem had been obtained by diligent attention to detail, and all follow-on Apollo/Saturn upper stages would be modified accordingly for successful completion of all forthcoming booster missions. Management's insistence on a plausible and acceptable explanation for the surprising flight data certainly prevented future mission failures based on an inadequate igniter line design.

This case study is also an excellent example of strong team spirit, leadership on several levels and outstanding motivation to get to the bottom of problems.

Management certainly earned its pay in this instance, since the problem was hidden and not easily visible. Communications up and down the line were excellent and contributed to the solution. Once the shortcoming had been uncovered, very definite and positive action was directed.

Case Study #8: Stress Corrosion Problems

Stress corrosion, as it was encountered with the Saturn launch vehicles, is an example of a problem handled essentially by the engineering level.

Top management paid attention to this problem only in the final stages of the program when such problems were discovered at the launch site.

a. Discovery of Initial Anomaly

A control actuator failure occurred early in the program during an engine test. Subsequent inspection revealed that this malfunction was caused by the use of stress corrosion susceptible material for the actuator housings and other parts of the actuator.

The MSFC laboratories were fully aware of the problem of stress corrosion. The ideal situation would have been to avoid by design all stress corrosion susceptible materials completely. These materials are affected by their environment, are "time oriented", and are dependent upon the dynamic structural loads while in the critical environment. Considerations must also be given to the way a particular material is processed, such as heat-treating. The designer is often forced on the basis of excellent strength, cost, weight, and delivery considerations to work with some of these susceptible materials. In such instances, the designer completes a stress corrosion analysis based on all information known to him for all the critical parts that would be subject to stress corrosion.

b. Initial Remedial Action

As a result of finding this initial anomaly, the materials group recommended an effort to create "visibility" by identifying all stress corrosion susceptible materials that were used in critical applications on the launch vehicle. These criticality analyses determined the manner in which a part was manufactured and the stresses that it was exposed to in the application. These analyses categorized also the various components of the vehicle as to their criticality to the overall mission performance of the vehicle. In those cases where a component was identified as critical to the vehicle function, special inspections were made mandatory on a periodic basis. Quality control people were given special training on the discovery and analysis of cracks found during these inspections. This action was accomplished by NASA as well as contractor personnel, and was normally covered under the basic contract obligations, which permitted implementation on a rather informal basis.

In addition to these routine inspections, NASA conducted independent tests to confirm the analytical results obtained by the contractor. In this way, a good understanding of the extent of the problem was reached.

A major effort was initiated to avoid the stress corrosion susceptible material by design changes. Whenever the material problem could not be resolved, special processing of the material was defined in the specifications, which for the most part improved the situation.

c. Discovery of Additional Problems

During a routine inspection of one of the manned Skylab Vehicles on the launch pad, an inspector discovered a crack in the stabilization fin of the first stage. He recorded his findings and had others re-inspect the fin. Because of the criticality of the part, materials specialists visited the launch site for additional analysis. They confirmed that there were cracks in the fin. This included some castings which were part of the fin. The location was critical for the flight of the vehicle and the success of the mission. The salt atmosphere at the launch site was a definite influence to which the vehicle was exposed on the pad. It was not possible to determine how long the cracks had been there.

A detailed study showed that the earlier analyses accepted the material for use on the basis that it would be manufactured in a certain manner using specified processes. In tracing back through the records, it was found that certain parts were fabricated and processed in a different way than the previous parts. The contractor had initiated purchases with a qualified supplier. When more parts were needed the contractor used different purchasing methods to obtain these parts. As a result, the parts were obtained from a different manufacturer. Until the detailed search of records was made, the contractor did not realize that these parts had been processed in a different manner. The company providing the parts was a second or third tier supplier; therefore the contractor was not the direct purchaser and as a result, was unaware of the different processing.

d. Remedial Action

Skylab program management ordered a review of every stress corrosion susceptible piece of material on all manned launch vehicles. Contractor and NASA engineering and materials personnel were requested to conduct separate analyses: The contractor was required to review his parts and provide information in a matrix format on each one of the vehicle parts. As the contractor finished his analyses, he would present his data to NASA engineers, who would review the material and examine the contractor's rationale for accepting a part made out of a susceptible material. Additional information on those items was required. Through this process, a complete re-analysis was made of all materials and their stress corrosion susceptibility. The assessment made of the cracks found in the fin was that the vehicle was not impaired structurally. The results of all the analyses were also presented to the Program Director of the Apollo-Soyuz Test Project, which will use a launch vehicle with the same problems. Except for continuing surveillance and scheduled inspections within 48 hours of launch, no changes have been proposed.

e. Conclusion

These instances of stress corrosion problems on engine actuators and the fins were not a result of management inadequacies. The problems discussed above developed as a result of time, actual stresses, and the environment. The management action taken was to re-examine in greater depth all materials for their stress corrosion susceptibility for possible elimination through use of a different material or process. In some cases, it was

determined that the cracks which did develop would not impair the vehicle structurally. To obtain the required authorization, an assessment was made of the cracks and the load carrying responsibility of the cracked parts. Each crack assessment was initially reviewed with stage and project management and again at the "Flight Readiness Review" conducted by the Program Director.

In summary, the management technique applied was one of diligent investigation and review of previous work without requiring high level attention or direction except for final approval. It is based on the philosophy to leave no stone unturned, but to pay great attention to even apparently minor detail. Responsibility has been delegated all the way down the line. Field inspectors uncovered the problem and implemented action. Engineering has always been aware of the problem but has not been able to avoid it completely. "Visibility" of encountered risks make top level management fully aware of the situation which they have to approve. Some people have claimed that launch vehicles have always flown with cracks, and that the implemented precautions are overdone. The only answer here is the success of previous flights, which management wants to retain under all circumstances for the few forthcoming flights. It appears, therefore, to be a worthwhile "insurance premium" to maintain the previous flight record.

Case Study #9: The Delta Project.

a. Background

This project was selected for study and analysis because it is by now the most seasoned effort undertaken by the Space Agency since its inception in 1958. Many more launchings have been planned for the coming years, and this program must therefore be appraised as a most successful one; it has an excellent reliability record and may therefore well survive the arrival of the Space Shuttle in the 1980's, since it provides great flexibility for the experimenters, good performance to geosynchronous orbit and for escape missions, while the Shuttle will require additional propulsion systems for such high-energy requirements. For these reasons, the Delta configuration may very well be rather cost-competitive with Shuttle flights especially for the smaller payloads with quick turn-around times.

b. History

The Thor-Delta project was the first launch vehicle effort to be organized by the newly created Space Agency in 1959. It had its origin in the U.S. Air Force-developed Thor IRBM missile, which had previously already been combined with the 2nd and 3rd stages of the Navy-Vanguard missile as the Thor-Able project (U.S. Air Force). The Thor had been developed in the 1950's by the U.S. Air Force on a crash basis to close the missile gap with the

USSR by the establishment of an interim capability in the form of the Intermediate Range Ballistic Missile (IRBM) with a 1,500 mile range. Simultaneously, the U.S. Army was developing the Jupiter-Missile, which had many similar features. Both IRBM's were eventually deployed in Europe, but have since been withdrawn when the Nation's ICBM capability became available. While much of the Jupiter design and many of its components formed the basis for the Saturn launch vehicles for the Apollo Program, the Thor was the basis for a long line of ever-improving launch vehicles of the Delta-series.

This project was undertaken by NASA as an interim step. Accordingly, it consisted initially of only 12 launch vehicles to be used as boosters for several spacecraft projects which were under way and ready for early launchings. The Delta project has been growing ever since then, and its end is not yet in sight, although a number of future problems are shaping up, calling for drastic decisions in the not-too-distant future.

The project got off to a rather shaky start when the first launch in May 1960 turned out to be a failure. However, the second attempt could be undertaken only 3 months later and resulted in orbiting the widely hailed Echo balloon, the first spacecraft which was generally visible to the

naked eye. The remaining 10 vehicles of the initial order performed also rather well and orbited such well-known spacecraft as Tiros, Ariel, OSO-1, and the commercially-oriented (AT&T) Teistar. Indeed, the demonstrated reliability of the Thor-Delta project as well as its flexibility prompted NASA to provide a permanent status to this launch vehicle in the NASA stable.

c. Delta Management Philosophy

Ever since the Delta project obtained permanent status in the launch vehicle stable of the Space Agency, project management has pursued the philosophy to gradually upgrade the launch vehicle capability whenever such improvements could be obtained without significant increases in the cost of the hardware, its preparation, checkout, and launch. Such improvements were also always geared to actual requirements of the many customers, who posed ever increasing demands on payload capability due to the sophistication of the spacecraft systems and associated experiments. Judicious application of cost-effectiveness considerations and careful engineering analysis has increased the Delta payload capability manifold, while the cost of the vehicle hardware and its launch has only doubled since the early 1960's. Considering the money inflation which has grasped all other projects as well as the spacecraft, this is an envious result, since the "cost per pound in orbit" is now considerably less than it was in the beginning of the program (more than a factor of 10!)

Performance improvements were introduced all along the line. Delta project management is proud to point out that the first launch of an improved configuration has never led to a flight failure. Credit for this must be given to tightly controlled and well supervised Configuration Control and thorough analysis of the effect of proposed changes on the entire system.

Typical improvements include uprating of upper stages, advanced guidance systems, larger propellant tanks, and especially an augmentation of take-off thrust by strap-on solid rockets. Improvements will be maintained once they have been introduced; no units will be produced with the outdated design.

Delta Management has introduced this policy of continued upgrading for two reasons: the ever increasing user demands, and the recognition that it increases reliability. It permits upgrading of components with better reliability characteristics and prevents that engineers and technicians become stale and bored. It appears that Delta project management has succeeded to create an excellent team spirit. The morale is high, and the desire to add to an already excellent record of performance is utmost in everyone's mind.

d. Reliability of the System

The issue of reliability has been uppermost in the minds of the Delta managers ever since the initial failure. The current environment of fewer but more costly research and development spacecraft as well as the fact that the Delta vehicles are being used extensively for commercial ventures as well as for foreign flights adds impetus to profit and loss considerations of these associates. A strong desire to further increase the overall success ratio is therefore in existence. The management approach in this area has been an evolutionary process. The first Delta contract in 1960 merely stated a reliability of 90% as a design goal. Subsequent contracts incorporated various incentive clauses to emphasize the requirement for high probability of success. A bonus was awarded for each successful mission, and a penalty will be assessed for all those missions which are judged as failures. The amounts of the bonus and penalty have varied, but the penalty is normally about ten times as large as the bonus, which has been a very strong inducement indeed. This would be representative of a 90% reliability performance, and only when the contractor obtains a better ratio than that will he earn additional awards. The program has demonstrated a better performance than that, and it is expected to improve even further in the future. This must be considered as a very respectable performance under consideration of the limited funds which have been available to unmanned programs like the Delta project. It should not

be compared with the Apollo program, where much more ample funds were allocated in order to obtain "man-rated" performance characteristics. The Delta project is making use of some of the Apollo components in order to improve the success ratio of the project.

e. Summary

As is evident from the previous paragraphs, the Delta project is being planned under entirely different auspices than the Apollo program. In this latter case, most of the planning was done "upstream", while only very little reprogramming of basically different technical approaches took place. Most of the reprogramming for Apollo was to meet mishaps, schedule delays, cost problems, etc. For the Delta project the situation is entirely different. Only very little planning was done "upstream" and most of the planning has ever since then consisted of logical replanning to meet the new customer requirements and to meet higher reliability goals. This planning must be accompanied by continuing systems analysis and detailed systems engineering to assure interface compatibility, and to accommodate the future customer needs. Continued customer-project relationships must therefore be established and maintained.

However, this continuing analysis work seems to appeal to the engineers, designers, and technicians, and has apparently built up a tremendous team spirit that equals the one that existed during the Apollo days. This feature seems to be one

of the most important ones of the project. Without it, it might easily run into problems and launch failures, which just cannot be tolerated at this time.

In the meantime it appears that project management is keeping its eyes and ears open for future improvement possibilities, since the competition from the Shuttle will be tough. The Delta launches will have to be able to demonstrate the potential for further improvements, a continued high reliability and success ratio, and a large amount of flexibility in schedules and integration requirements to the experimenters. In that case, the possibility for a continuing program is good. In any case, by 1980 the Delta project has had a lifetime of more than 20 years, which is much better than the life expectancy of most projects of this type at this time period. Even the Space Shuttle is only planning for a 20 year operational period. For a program which was started on an interim basis, like the Delta project, it has performed in a marvellous fashion.

The reasons for its success appear to be a continuing demand for this type of service based on NASA's responsiveness to customer needs. Management always paid attention to detail to avoid mishaps. An excellent team spirit assured quality performance and reliability. These success-oriented management philosophies have provided outstanding motivation for a team which carried this "interim" program to such long lasting performance records.

Case Study #10: Applications Technology Satellites (ATS) Program

a. Overview

The launch of the Applications Technology Satellite F
—(ATS-F) on 30 May 1974 has been called the most important
35
launch of 1974, since it will advance communications technology
and their applications greatly, and since it demonstrated NASA's
payload capability in the years prior to the Shuttle availability:
A Titan III-C rocket carried a payload of more than 3000 pounds
into geosynchronous orbit, which will represent maximum US
orbital capabilities for some years to come.

ATS-F was renamed ATS-6 after a successful launch. It is a
complex, but most versatile and powerful communications spacecraft,
which will operate over the next two to five years from several
selected orbital positions in geosynchronous altitude, and will
serve as an international experimental broadcasting station
in space. It is powerful enough to beam signals directly to small
ground receivers, which can be produced rather inexpensively.
Of greatest interest are health and educational television programs;
but ATS-6 carries a total of 22 sets of equipment which can
conduct 40 scientific and technological experiments, many of them
international in their scope.

35) NASA Activities, "ATS-F Launch" May 15, 1974, Volume 5,
Page 98.

b. History of Communications Satellites³⁶

ATS-6 is the latest in a unique series of NASA "Application Technology Satellites (ATS)", which are to collect and confirm data for various space flight technologies and applications, especially in the field of communications.

The underlying management philosophy of the ATS-program has been to be responsive to the communications-oriented customer by the design, launch, and operation of multiple-mission satellites. Flexibility to meet changing requirements will demand adaptable and versatile mounting provisions for a variety of experimental payloads. This is to be done at reasonable cost and on a schedule compatible with the experiments availability. This philosophy led to the need for major technological advances, which eventually led to concepts in functional systems as incorporated in the ATS-F spacecraft.

c. ATS-F/ATS-6 Satellite

Program management proposed a major increase in spacecraft size and communications capabilities over the initial series of spin-stabilized satellites³⁶; a new principle of 3-axis stabilization was mandatory for these improved capabilities calling for

³⁶⁾ The ATS-F Data Book, A Publication by the Goddard Space Flight Center, Greenbelt, Maryland 20771

new concepts and a major redesign of the spacecraft. The NASA Field Center (Goddard), which had administered all previous ATS contracting, started a phased program planning activity in 1969, which led eventually to 3 parallel Phase A (feasibility) studies with the General Electric Company, Fairchild Industries, and the Lockheed Corporation. After completion of this Phase, two contracts for \$5 Million each with the General Electric and Fairchild Industries conducted Phase B/C definition and design activities for the finalization of such a novel spacecraft. The contract for development and construction was initially awarded to the General Electric Company. However, the competing contractor objected to the NASA selection, and after a review under GAO auspices, the final award was made to Fairchild Industries. This protest and the subsequent change in contractors has probably led to a better definition of the spacecraft and all its subsystems than would have been obtained without the extra effort. In any case, the final execution of the ATS-F program led to a very successful development in a rather rapid sequence of events, in spite of the contractual requirement to integrate a number of preferred design features of the competing contractor. A very successful launch with a Titan III-C launch vehicle on 30 May 1974 started a most successful operational period of the many experiments during the initial operation of the ATS-6 over the United States, where it is now conducting communications experiments for HEW, local Governments, health organizations, and other governmental and scientific organizations,

until it will be repositioned for a year over the subcontinent of India for an international education experiment for the Indian Government.

d. Program Appraisal

In spite of the launch vehicle problems for ATS-2 and 4 -- which were thoroughly investigated in the established manner -- the ATS program has been appraised as a very successful one, especially in regard to the most recent launch of ATS-F/6. What are the reasons behind such success? Of special interest is the question how different is the management from that of Apollo?

One apparent difference is in the planning process. Most of the Apollo planning was done right at the beginning of the program, and only very little reprogramming occurred during its execution. A minor amount of lunar and in-flight experimentation was added during Apollo. The major change was the addition of the lunar rover which in spite of its importance in regard to exploration results represents only a rather small fraction of the total Apollo effort. In case of ATS it is evident that a lot of replanning occurred all the way along the line. This is natural and explainable by the main objectives of the ATS program, mainly to advance the "state of the art". This planning method will make it impossible to arrive at firm total program costs at the outset. It will provide maximum flexibility

for incorporation of latest technologies and be highly responsive to latest test results from previous flights. The entire management structure and program control is laid out for this specific purpose. It must also be considered that the entire program is much smaller in scope than the Apollo Program was. It lends itself to greater flexibility in programming, and less rigidity in the overall structure of the program, even being able to change objectives. This is also made possible by the fact that the ATS-program was never as much in the limelight of public attention as Apollo was at some time. This permits much greater flexibility to all kind of reprogramming measures without any public pressure. Strictly scientific and technological considerations can make up the ground rules. This will enhance the appeal to the scientific community, and to all the users. The details of the program can always be responsive to the latest needs and desires, as long as they can be accomplished within the established scope and overall framework.

Another outstanding feature that was found is the great amount of team spirit and dedication. Everyone on the team was willing to work long hours, to track down problems until they have been solved, to find better ways of doing things, to be responsive to the scientists, to meet demanding international requirements, to be open and candid. The government-contractor team appeared often

as really only one crew. There was great mutual understanding, maximum responsiveness to new needs, and a willingness to help the program and to improve its performance. The location of the Government team and of the contractor operation seemed to have beneficial results on such cooperation. It was relatively easy for the Government to participate very strongly in all phases of the ATS development by just moving over to the contractor plant for a while, and by participating in all important steps. This situation and the inherent flexibility determined also the actions taken in regard to apparently the greatest problems: The cooperation with the immensely large group of customers, often being of international scope. In this area, the ATS problems appear relatively to be even larger than the ones on Apollo, due to the deep involvement of scientists in this program, while Apollo was essentially an operational problem with relatively little scientific involvement.

The existing management systems and organizational arrangements seem to be fully adequate for these difficult tasks of experiment accommodation and integration. The established management philosophy supports these activities to the highest possible degree.

Case Study #11: Lunar Orbiter Project

Background

The Lunar Orbiter Project which was one of NASA's unmanned projects was considered highly successful. There were five flights in five attempts during a one year period, all successful. Lunar Orbiter I which was launched August 10, 1966, was the first U.S. spacecraft to orbit the moon. Lunar Orbiter V, the last in the series, was launched August 1, 1967.

The first three Lunar Orbiters essentially satisfied the primary objective to obtain high resolution photographs of proposed Apollo landing sites. The fourth Orbiter systematically photographed the near side of the moon and the fifth Orbiter completed the far-side coverage.

The five Orbiter spacecraft returned over 1654 high quality photographs taken from lunar orbit. Each spacecraft was similarly equipped with two cameras which operated simultaneously and had the same line of sight but different fields of view and resolutions. The cameras utilized a common supply of 70-mm film and the dual images they recorded were referred to as medium-resolution frames and high-resolution frames.

The primary emphasis was not only to support the Apollo program but to provide more detail in many areas that had been studied from earth-based observation. At the average Orbiter altitude of about 3000 km for the photographs, the resolution of the two cameras were approximately 500 meters and 65 meters, whereas under favorable conditions, earth-based photography of the moon reveal details only as small as 500 to 1000 meters.³⁷

37) David E. Bowker and J. Kendrick Hughes, "Lunar Orbiter Photographic Atlas of the Moon," NASA SP-206, 1971, page 1.

Management Approaches and Philosophies

What were the ingredients which made this project such an outstanding success? It turned out that there were many factors which contributed without any one factor being the dominant or most critical one. Just about everything went right for the project. First of all, since the project was a direct Apollo support activity, it had well defined and easily recognized goals and schedules. This is, all personnel working on the project were aware of its importance in relation to Apollo and also were cognizant of the need to meet their schedule commitments. Also, the NASA (Langley Research Center) and industry (The Boeing Company) team both enjoyed the reputation of taking on only those assignments they knew they could accomplish.

NASA set the tightest possible schedule. The development and flight of the first spacecraft was to be made in 26 months. It was completed in 28 months. Even though the final costs exceeded the preliminary estimate by 50%, it was far less than the price rise normally experienced in other projects where total costs often were double or triple the first estimate.³⁸ It was also felt that the higher costs experienced were somewhat offset by the wide expansion of the project objectives. Originally the only objective was to find smooth lunar landing areas for the Apollo spacecraft. In addition to this, the lunar orbiter provided enough photos to map the back side of the moon.

The Lunar Orbiter objectives were specifically directed toward Apollo requirements and toward the general scientific exploration of the moon and its vicinity. The objectives consisted of three general categories of information to be obtained. These were 1) Apollo, photographic which consisted of site certification and selection, landmark mapping, and geological survey; 2) Apollo, non-photographic which consisted

38) "Lunar Orbiter Team Lauded for Effort as Program is Ended", Aerospace Technology, September 11, 1967, page 18.

of gravitational field, micrometeorite flux, and high-energy particle flux; and 3) General scientific which consisted of radar reflectivity, magnetic field, and thermal (IR) mapping.

The project was organized with program direction at NASA Headquarters, project direction at Langley Research Center, prime contractor—the Boeing Company, launch vehicle responsibility at Lewis Research Center, launch facilities at KSC including use of the Atlantic Missile Range (AMR), and ground based tracking and mission control at Jet Propulsion Laboratory.

The major project constraints were 1) launch with proven vehicles (Atlas-Agena), 2) spacecraft designed with conservative weight limitations, 3) launch from KSC, 4) flight operations and control from Deep Space Network (DSN), and 5) maximum use of space flight qualified components.

The project manager at Langley Research Center was strongly people oriented. In looking back over the project he had no hesitation in pointing out the importance of people as the single most important element of the project management approach taken by Langley on Lunar Orbiter. He enumerated four standards for project personnel management governing Lunar Orbiter at Langley. These were:

1. The right people with the right specialization were carefully selected to fill each individual slot in the project office.
2. Thorough consideration was given to the compatibility of individuals with other personnel in the project organization.
3. Heavy emphasis was placed in the selection process on the past demonstrated ability of candidates to dedicate themselves totally to activities focused on achievement of a given objective.
4. Managers at all levels of the project organization gave full recognition to the importance of maintaining "esprit de corps" and enthusiasm on the part of all project personnel in working towards fulfillment of project goals.

The Boeing project manager described the Langley-Boeing relationship as follows. "The constant presence of highly qualified and exacting customer (NASA) personnel could

have created a difficult situation. This, however, turned out to be an asset. The attitude of the NASA people demonstrated the importance of the project and their dedication to it. Boeing employees were equally dedicated and the small size of the project and proximity to hardware established a real sense of belonging to the team. This attitude carried the project through many trying and difficult times." Good communications between Boeing and Langley were further assured by the frequency of reviews and meetings between the two.

The establishment of an efficient work breakdown structure contributed substantially to effective contract management. Costs of each individual task could be accurately measured.

Lunar Orbiter broke new ground in a number of management systems. It was the first space project to apply NASA Publication NPC250-1, Reliability Program Provisions for Space System Contracts. For Boeing, the project represented the first application of PERT and Companion Cost as the sole management control system. They were adopted with full intent to make them work. However, none of the Boeing managers cited PERT as a factor in the success of the project, although credit was given to "central scheduling and status reporting" as a contributor to effective management. While the formal reporting and control systems contributed significantly to the success of Lunar Orbiter, all those involved in the project attributed a great deal to the ease of informal communications, the encouragement given by both customer (NASA) and contractor management to full and free exchange of information, and the contractor's concern for keeping NASA fully informed on all potential problems.

All changes to the design were held to an absolute minimum. Before a change was presented to NASA for approval, it had to be approved by the contractor's project manager. This limited changes to only those critical to the mission performance.

The early involvement of a strong ground testing program also contributed to the project's success.

All of the above dealt with those items which contributed to the success of the project. There were some items which lessened the project's management effectively. One of these

was the incompatibility in contract form between the prime contractor and the principal subcontractors. It appeared that both NASA and Boeing were slow in recognizing the need to pin down the subcontractors to a commitment such as an incentive contract before start-up of development operations. The absence of incentive provisions in the two major subcontracts left Boeing with little leverage over control of the subcontractors. Although the results, which might have been gained by use of subcontracts with incentive provisions remain hypothetical, it appears that cost overrun penalties might have held down some of the substantial overrun costs in the photo system.

Summary and Conclusions

The Lunar Orbiter project was a relatively short range project that for the most part utilized existing technologies. The first flight was accomplished in 28 months and the last flight was one year after the first flight. It also required a relatively small amount of people. For the most part, it utilized off the shelf components and existing qualified launch vehicles.

The basic management philosophy was one of selecting the right individual for each job. The individual was not only considered for his technical competence, but also his capability to get along or be compatible with others in the organization with which he would have to interface.³⁹ NASA developed a definitive contract for the prime contractor to meet. The prime contractor was intent on meeting the technical and schedule requirements of his contract almost to the point of creating excessive cost overruns. As mentioned previously, some of the cost overruns were the result of not having a tight or incentivized contract with the subcontractors.

39) Erasmus H. Kloman, "Unmanned Space Project Management, Surveyor and Lunar Orbiter", NASA SP-4901, 1972, page 17.

Both NASA and industry personnel working on this project were highly motivated. They were aware of the importance of this project to the upcoming Apollo program, and as a result, put forth effort which was many times over and above their normal obligations. With this type of effort and interest on the part of everyone concerned, the Lunar Orbiter Project became the success that it was.

F. Conclusion

When this research study was started about a year ago, it was hoped that a few outstanding characteristics of managers or management approaches could be uncovered which would assure success for the conduct of a program. The only "tall poles" that could be found and that could demonstrate importance to program management were the three statements:

"Attention to detail"¹⁷
"Leave no stone unturned"¹⁸ and
"Be aggressive--not passive"⁸

Because of their generality, these statements were initially not even recognized as "tall poles" but an analysis of their implications for the conduct of a program gave finally reason to believe that these philosophies create policies and management methods which are highly conducive to program success. They lead to comprehensive and complete planning, to include successful integration of people and facilities for optimum project performance. Such "team" should contain the best available experts in those fields that are of importance to the program. Flexibility in approach, employment of personnel and utilization of facilities should be a key element of the plan. Such flexibility was demonstrated by the rather late introduction of the "all-up" concept for the Apollo Program as well as "open-ended" planning for many flight missions. Task teams, Tiger Teams, working groups and similar temporary assignments demonstrate

17) George M. Low, "What Made Apollo A Success?", page 45.

18) Wernher von Braun, Interview, Summer 1974.

8) Lee B. James, "Management of NASA's Major Projects", page 3.

how great flexibility in the deployment of personnel can be obtained to good advantage for the project. No additional staffing was needed for these activities. Management drew on the manpower of the existing organizations. The Saturn Program has in time applied all phases of organizational arrangements from the purely functional organization, through the Matrix arrangement to the totally project-oriented set up. Methods of directing and controlling have always been kept flexible by all levels of management in all discussed NASA projects.

A more detailed summary of the impact of the above mentioned philosophies is given in the next paragraphs. They are arranged in typical textbook fashion in the 5 major areas of management activities.¹⁵

Planning

This most vital management function must cover all phases and portions of the program and must consider influences from outside of the project. The magnitude of the task to be tackled must be appraised with realism. All resources that are needed to do the job must be clearly defined at the outset. Of further importance is the optimization of relationships of all team players to each other and to their "interfaces" with the outside world, as well as with the material and equipment at their disposal.

All key participants must have inputs into the initial definition of the project, as well as a continuing part in the final decision making processes. The role of the manager here is essentially to assure the desired wide participation, to solicit the right kind of analyses and studies, to receive the inputs for his own evaluation, and to finally present the selected modes of operation, technical design, organization,

15) Harold Koontz and Cyril O'Donnell, "Principles of Management", McGraw-Hill, 1972.

and other key elements of the integrated program, to his superiors. These may be elements outside of the Agency which administers the project.

The integration of participants is of utmost importance for the success of any large project. Accordingly, NASA placed considerable emphasis from the beginning on complete technical and managerial integration of all project personnel. These consisted of members from several NASA Centers, NASA Headquarters, large and small industries, other Government Agencies, scientists from academic institutions, and sometimes even foreign participants, especially in the areas of scientific experimentation. This brief summary of the key planning functions indicates already that problems of organization, staffing, directing, and even controlling have to be considered simultaneously with the technical requirements which often contribute less to the managers problems than these other areas.

Other studies⁴⁰ have also found that one of the most important ingredients to success is the support by Top-Level Management, going all the way up to elements possibly even outside of NASA. In the instance of Apollo, presidential and congressional support were such vital elements. It appears to this investigator, that without this support completion of the lunar landing might well have been endangered.

For this reason it appears most desirable that specific milestones in the program plan be established to bring progress to the attention of those who provide such support. The budget cycle may well be used for this purpose. In the mid-term and lunar landing phases of Apollo, the general publicity by television and other news media accomplished this task automatically. This was not true any longer for the final phase of the Apollo program, nor for any other NASA project.

40) David Charles Murphy, Bruce N. Baker, Dalmar Fisher, "Determinants of Project Success" --School of Management, Boston College, Chestnut Hills, Mass. 1974.

Since program planning is of such vital importance to any large project, Chapter D- "Impact of "Management Philosophies on Major NASA Programs" has given a brief description of a few typical management decisions made early in the Apollo program.

Organizing

A suitable organizational frame work is the key to the successful execution of any program. As was shown in case of the Saturn/Apollo program, the top leadership in NASA had recognized from the beginning that the magnitude of the lunar landing would not permit that just one group of people would be able to perform the task with their available resources. It was considered necessary from the beginning to plan for teamwork. Excellent cooperation became a vital element to accomplish the work. The project team was to be composed of members from all NASA Field Centers, small and large corporations from private industry, elements of the military establishment, and universities. This program was visualized as a national endeavour. No concentration in any one locale would be considered acceptable. Therefore, as many of the States and industrialized regions of the Nation as possible had to be included in the team. The role of NASA Headquarters Offices was from the very beginning to organize such national efforts and to provide for proper management of such a variety of team members. In spite of these provisions it became necessary at several occasions to establish special task teams to solve particular problems. These teams reported to top-level management. Their activities were of short duration; the teams were disbanded as soon as the special assignment was completed.

Staffing

It was evident from the outset of the Apollo Program that the technical requirements for the accomplishment of the task were so demanding that ways and means had to be found to bring the Nation's topmost experts to bear on the program. This was particularly true for such engineering challenges as presented by the requirements for immense rocket power for vehicle lift-off; the need for guidance and navigation accuracies to steer the space-craft to tremendous distances and to guarantee safe return from the moon. Similar tasks had been performed before in other NASA programs; but now the requirements for dependability and reliability had to be increased immensely since human lives were at stake and the manned program could not tolerate the risks that had been taken previously. Backup capabilities and multiple redundancies were introduced. The Nations leading experts in Government and private industry were called upon to participate in these new endeavours. In the case of rocket power, the in-house capabilities of the Marshall Space Flight Center were used extensively in "Arsenal Management" methods to utilize the available NASA knowledge, heavily supported by contractor efforts.

It was concluded early in the program that extensive use of computer technology would be needed to accomplish the tasks. It became, therefore, necessary to acquire the people who could develop new computer systems, associated computer "software", and the broad scale application schemes of this new technology in many areas which were new to this kind of exposure.

On the other hand, it was recognized that all these teams should be kept small to keep the program within fiscal limits. But even more important was management's desire to provide a continuing challenge to those top level experts in order to keep their interest alive.

Directing

Broad application of teamwork philosophies laid the corner stone for the success that has been displayed in all major NASA projects, but especially the Saturn/Apollo program. This was possible, although a teamwork arrangement does not necessarily make project direction easier. To make the project team perform efficiently, NASA Headquarters established centralized program control in Washington as the hub of operations. Decentralized project execution at the Field Centers implemented the program requirements for all efforts at the contractor sites or Government owned assembly, test and launch facilities. The program manager at NASA Headquarters looked after the Agency's broad interests, while contractor and Field Center Directors assured successful execution of the project as well as timely quality performance in all instances.

The Project Managers provided active leadership in all above specified areas and had the full and whole-hearted support of Center Management as well as from NASA Headquarters elements. This system also provided for quick response, flexibility ^{AND} coordinated communications.

Controlling

The implementation of the above outlined policies will lead to the following features of a Management control system. Such system was applied to the Saturn/Apollo Program, and with small deviations to many other NASA projects of similar nature. It is described in good detail in the often-quoted James report.⁸ For this reason, it shall suffice here to just summarize a few typical control system highlights:

8) Lee B. James, "Management of NASA's Major Projects".

1. Absolute concentration of all resources in the hands of the manager, to be applied to critical events or problem areas at his discretion on short notice.

2. Shared authority with others, but clearly focussed responsibility in the hands of the manager and his designated agent for specific actions.

3. Delegation of decision making authority to the lowest possible level in the organization for quick response and optimum decisions based on correct and up-to-date information. ("Working Level" involvement throughout the program.)

4. Emphasis on communications to assure complete understanding of objectives, approaches, and requirements by all team members; stress on "visibility" of all actions.

Apollo program management put greatest emphasis on program controls¹⁴. The utilized control documents and/or functions are summarized in the enclosure. A very detailed description of the Saturn Management Control Room and its operation is included in "The Saturn Management Concept".¹⁶

14) Samuel C. Phillips, "Management Scheme for Apollo", page 195.

16) Roger E. Bilstein, "The Saturn Management Concept."

G. "S U M M A R Y"

The results of this study indicate that there appears to be no single, outstanding characteristic of program management that will assure success. It was found that neither the characteristics of the program manager, nor a specific organizational structure deserve the sole credit for a successful program. It was also determined that neither specific management methods nor operating procedures can be singled out for such distinction. In fact, management, organizational arrangements, use of methods and procedures underwent several changes during the studied NASA programs.

If there are any characteristics that deserve particular emphasis and that should lead to program success, they are--on the basis of this study--top level support; clear definition of program objectives; the amount of dedication that the manager and his team bring to the job; the communication between them, and to the outside; their knowledge and expertise in respective fields of endeavour, and motivation to accomplish the objectives in time, on schedule, and within the framework of established constraints. It is the manager's prime task to generate for his project the conditions that make the realization of these characteristics as likely as possible. He can accomplish this by proper application of conducive management philosophies which emphasize "aggressive action" - "Attention to detail"- "To leave no stone unturned"- and to proceed with the formation of a strong team to assist in the conduct of these tasks.

The selected 11 case studies have served to demonstrate some of these implications. NASA's senior management was aware from the beginning that objectives, people, and facilities could only be successfully integrated if superior management methods were applied. Approaches of the early sixties were not believed to be satisfactory without modifications and improvements, although they set the general pattern for the finally utilized systems.

Accordingly, NASA generated an extensive set of management instructions, handbooks, guidelines, specifications and other

pertinent information. These are well documented in the articles by Robert C. Seamans, Jr.,¹³ by Sam C. Phillips¹⁴ (see also Enclosure) and by the Lee B. James report on "Management of NASA's Major Projects".³

This information has been used for the recently completed Skylab Program, and will be utilized again--with certain improvements and modifications-- for the Space Shuttle project and its application to large-scale earth and space exploration.

It can be expected that the discovered management philosophies can also be applied to non-aerospace programs. It appears however, that NASA's management methods, procedures, and documents will require careful appraisal and adaptation, just as they do for new NASA projects. The existing information and documentation provides a huge pool of data from which effective tools can be obtained that will aid in the management of future programmatic challenges.

<p>DEFINE PROGRAM REQUIREMENTS BASELINE</p>	<ul style="list-style-type: none"> • Work Breakdown Structure • Development Plans • Specification Tree • Matrix of Key Documents 	<ul style="list-style-type: none"> • Phased Project Planning • Work Statements • Incentive Structure • PERT Logic Nets
<p>MEASURE PERFORMANCE</p>	<ul style="list-style-type: none"> • Data Management (MICS) • Reporting Systems • Scheduling System • Design Reviews & Checkpoints 	<ul style="list-style-type: none"> • PERT Runs
<p>ANALYZE & ASSESS</p>	<ul style="list-style-type: none"> • Weight /Performance Trends • Schedule Effectiveness • Value of Work Index • POP Reviews 	<ul style="list-style-type: none"> • PACCT • MICA • PERT Trends
<p>CONTROL/DIRECT CHANGES</p>	<ul style="list-style-type: none"> • Configuration Management • Interface Panels (PFB) • Contract Change Orders • POP Publication 	<ul style="list-style-type: none"> • Program Directives • Control Milestones
<p>ASSURE ACTION & FEEDBACK</p>	<ul style="list-style-type: none"> • Accountability • Formal Program Reviews • Management Surveys • "Eyeball-to-Eyeball" Meetings 	

THE PROGRAM MANAGEMENT PROCESS*

SYSTEMS, TOOLS, TECHNIQUES

ENCLOSURE

* Samuel C. Phillips, Major General USAF, "Management Scheme For Apollo" in Science and Technology Series, Vol. 12, "The Management of Aerospace Programs" (American Astronautical Society), page 197.

REFERENCES

- 1,2) Tom Alexander, "The Unexpected Payoff of Project Apollo", Fortune Magazine, July 1969 issue, page 114.
- 3) J. Gordon Milliken, "Aerospace Management Techniques: Commercial and Governmental Applications," University of Denver, Colo., November 1971- (NTIS-N72-14971)
- 4) Aerospace Management (A General Electric Publication) Volume 5, number 1, 1970, pages 101, 111, 119.
- 5) W.W. Hagerty, et. al. "Research and Education in Management of Large-Scale Technical Programs", Drexel University, Philadelphia, Pa. June 1973.
- 6) J. Von Puttkamer, "Apollo Management," VDI-Zeitschrift February 1973, Volume 115, Number 2, pages 89-99.
- 7) Thomas O. Paine, "The Relevance to Cities of Space Age Management" Address to the National Conference on Public Administration, Miami Beach, Florida, May 20, 1969.
- 8) Lee B. James, "Management of NASA's Major Projects", Report by the University of Tennessee Space Institute, July 1973. (NTIS-74N-10879)
- 9) Samuel C. Phillips, Lt. General, USAF, Apollo Program Director, address to the National Conference on Public Administration, at Miami Beach, Florida, May 20, 1969. "Management of Large Research and Development Programs."
- 10) Albert J. Kelley, Dean of The School of Management at Boston College, "Aerospace Management"
- 11) Robert A. Frosch, Assistant Secretary of the Navy for R & D. quoted in "Aerospace Management", Astronautics and Aeronautics, August 1970, Volume 8, Number 8, page 46.
- 12) Webster's Third New International Dictionary, (1965), "Philosophy."
- 13) Robert C. Seamans, Jr., "The National Commitment to Apollo-Action and Reaction"--Astronautics & Aeronautics, August, September, and October 1969, Volume 7, Numbers 8, 9, & 10 (The Minta-Martin Lecture 1968-1969), pages 32 ff., 44 ff., 64 ff.
- 14) Samuel C. Phillips, Major General USAF. "Management Scheme for Apollo" in Science and Technology Series, Vol. 12, "The Management of Aerospace Programs" (American Astronautical Society), pages 193 ff.

- 15) Harold Koontz and Cyril O'Donnell, "Principles of Management," McGraw-Hill, 1972.
- 16) Roger E. Bilstein, "The Saturn Management Concept" June 1, 1974, MSFC Publication NASA CR-129029.
- 17) George M. Low, NASA Deputy Administrator, "What Made Apollo a Success?" -Astronautics & Aeronautics, March 1970, page 45.
- 18) Wernher von Braun, Interview in summer 1974.
- 19) Eberhard F.M. Rees, Aerospace Management, 1967, Volume 2, Number 2. (General Electric publication.)
- 20) John P. Kushnerick, "The Fight For Spaceflight", Aerospace Management, September 1963.
- 21) William R. Lucas, "Political Bugs" Astronautics & Aeronautics, October 1972, Volume 10, Number 10, page 44.
- 22) John L. Sloop, "Looking For the Sweet Combination", Astronautics & Aeronautics, October 1972, Volume 10, Number 10, page 52.
- 23) David S. Akens, "Saturn Illustrated Chronology", MSFC, MHR-5, January 20, 1971.
- 24) David S. Akens, "An Illustrated Chronology of MSFC," MSFC, MHR-10, May 1974.
- 25) Wernher von Braun and Frederick I. Ordway III, History of Rocketry and Space Travel (New York, 1969).
- 26) Wernher von Braun and Fred Wipple "Moon, Man's Greatest Adventure", Harry N. Abrams, Inc.
- 27) Robert L. Roshott, "An Administrative History of NASA, 1958-1963", NASA SP-4101 (1966).
- 28) Beirne Lay, Jr., "Earthbound Astronauts", 1971 Prentice Hall, Inc.
- 30) K.H. Debus, "Final Report-S-IV All-Systems Stage, Incident January 24, 1964" (Internal NASA Report).
- 31) "The Kennedy Space Center Story"--U.S. Government Printing Office: 1974-740-742.
- 32) J.B. Gayle, NASA TN D-563, "Investigation of S-IV All Systems Vehicle Explosion", September 1964.

- 33) MSFC- Saturn V Semi-annual Progress Report of January 1967-
June 1967. MA001-005-211.
- 34) Erich E. Goerner, "Lox Prevalve to Prevent Pogo Effect
on Saturn 5", Space/Aeronautics, December 1968, Volume
30, Number 7, page 72 ff.
- 35) NASA Activities, "ATS-F Launch" May 15, 1974, Volume 5,
page 98.
- 36) The ATS-F Data Book, A Publication by the Goddard Space
Flight Center, Greenbelt, Maryland 20771
- 37) David E. Bowker and J. Kendrick Hughes, "Lunar Orbiter
Photographic Atlas of the Moon," NASA SP-206, 1971, page 1.
- 38) "Lunar Orbiter Team Lauded for Effort as Program is
Ended", Aerospace Technology, September 11, 1967, page 18.
- 39) Erasmus H. Kloman, "Unmanned Space Project Management,
Surveyor and Lunar Orbiter", NASA SP-4901, 1972, page 17.
- 40) David Charles Murphy, Bruce N. Baker, Dalmar Fisher,
"Determinant of Project Success"--School of Management
Boston College, Chestnut Hills, Mass. 1974.

NOTE: An excellent Bibliography on pertinent literature
is listed in NASA SP- 324, "Project Management in NASA"
by Richard L. Chapman, pages 123 ff.
Other reference material can be obtained from Lee B.
James, "Management of NASA's Major Projects" (see ref. 8).